Journal of Experimental Psychology

ARTHUR W. MELTON, Editor
HUMAN RESOURCES RESEARCH CENTER
LACKLAND AIR FORCE BASE
SAN ANTONIO, TEXAS

CONSULTING EDITORS

Judson S. Brown, *State University of Iowa*
Frank A. Geldard, *University of Virginia*
James J. Gibson, *Cornell University*
Clarence H. Graham, *Columbia University*
David A. Grant, *University of Wisconsin*
Lloyd G. Humphreys, *Human Resources Research Center*
Donald B. Lindsley, *University of California, Los Angeles*
Neal E. Miller, *Yale University*
Edwin B. Newman, *Harvard University*
Benton J. Underwood, *Northwestern University*
Delos D. Wickens, *Ohio State University*

Lorraine Bouthilet, Managing Editor

CONTENTS

Areal Effects in Foveal Brightness Discrimination: P. RATOOSH AND C. H. GRAHAM 367

The Effect of Alternating Views of the Test Object on Vernier and Stereoscopic Acuities: W. J. RICHARDS 376

Studies of Sensory Conditioning Measured by the Facilitation of Auditory Acuity: W. J. BROGDEN AND L. W. GREGG 384

A Comparison of Avoidance and Nonavoidance Eyelid Conditioning: F. A. LOGAN 390

Three Demonstrations Involving the Visual Perception of Movement: F. P. KILPATRICK AND W. H. ITTELSON 394

Generalization of a Muscle Action Potential Response to Tonal Duration: J. B. FINK AND R. C. DAVIS 403

Latent Learning in the Sophisticated Rat: ELIZABETH FEHRER 409

Dark Adaptation and the Humphreys Random Reinforcement Phenomenon in Human Eyelid Conditioning: D. A. GRANT AND H. W. HAKE 417

A New Technique for Observing Concept Evocation: M. R. MARKS AND C. K. RAMOND .. 424

Studies in Short-Duration Auditory Fatigue: I. Frequency Differences as a Function of Intensity: J. D. HARRIS, ANITA I. RAWNSLEY, AND PATRICIA KELSEY 430

Operant Extinction as a Function of the Extinction Schedule: D. H. BULLOCK 437

The Effect on Extinction Responding of Stimuli Continuously Present During Conditioning: C. B. FERSTER 443

The Effects of Auditory-Vestibular Nerve Pathology on Space Perception: C. W. MANN .. 450

American Psychological Association

Vol. 42 No. 6 December 1951

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

The JOURNAL OF EXPERIMENTAL PSYCHOLOGY is published monthly, two volumes per year, by the American Psychological Association, Inc. The subscription rate per volume is $7.00, or $14.00 annually. Single copies are $1.25. Subscriptions, orders, and business communications should be addressed to the American Psychological Association, Inc., Prince and Lemon Sts., Lancaster, Pa., or 1515 Massachusetts Avenue, N.W., Washington 5, D. C.

This JOURNAL publishes articles which are intended to contribute toward the development of psychology as an experimental science. Experimental work with normal human subjects is favored over work with abnormal or animal subjects. Studies in applied experimental psychology or engineering psychology may be accepted if they have broad implications for experimental psychology or for behavior theory. Normally, articles of a length exceeding 15 printed pages cannot be accepted. However, a single experimental study or an integrated series of studies accomplished simultaneously must be presented in a single article, rather than in a series of articles.

Articles are published in the order of their receipt, except in rare circumstances. Authors who request them are supplied with 50 free reprints without covers. However, under the new APA reprint policy no free reprints will be supplied to authors submitting manuscripts after January 1, 1952. All of the cost of the author's alterations in galley proof is charged to the author, and one-half of the cost of tables, cuts, and formulas.

Immediate publication can be given to articles whose authors assume the full cost of publication. Such articles must undergo the usual review by the Consulting Editors of the JOURNAL. No free reprints are given in the case of these articles.

Address all articles submitted for regular publication or for immediate publication to the editor, Arthur W. Melton, Human Resources Research Center, Lackland Air Force Base, San Antonio, Texas.

The JOURNAL adheres to the conventions concerning bibliographies, citations, preparation of tables and cuts, etc., as described by J. E. Anderson and W. L. Valentine, The preparation of articles for publication in the journals of the American Psychological Association, *Psychol. Bull.*, 1944, 41, 345–376. Special attention is called to the style of numbers and abbreviations (p. 353). The term 'experimenter,' with its various forms, singular, plural, and possessive singular and plural, is abbreviated *E*, *Es*, *E*'s, and *Es*'; analogous abbreviations are used for the terms 'subject' (*S*) and 'observer' (*O*). All manuscripts must be typed double-spaced throughout, including tables, footnotes, references, and titles for figures. Tables, figures, footnotes, references, and titles for figures must be placed on separate pages at the end of the manuscript.

Entered as second-class matter, February 6, 1937, at the post office at Lancaster, Pa., under the Act of March 3, 1879.

Acceptance for mailing at the special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized September 11, 1947.

Journal of Experimental Psychology

ARTHUR W. MELTON, Editor
HUMAN RESOURCES RESEARCH CENTER
LACKLAND AIR FORCE BASE
SAN ANTONIO, TEXAS

CONSULTING EDITORS

Judson S. Brown, *State University of Iowa*
Frank A. Geldard, *University of Virginia*
James J. Gibson, *Cornell University*
Clarence H. Graham, *Columbia University*
David A. Grant, *University of Wisconsin*
Lloyd G. Humphreys, *Human Resources Research Center*
Donald B. Lindsley, *University of California, Los Angeles*
Neal E. Miller, *Yale University*
Edwin B. Newman, *Harvard University*
Benton J. Underwood, *Northwestern University*
Delos D. Wickens, *Ohio State University*

Lorraine Bouthilet, Managing Editor

Volume 42, 1951

PUBLISHED MONTHLY
BY THE AMERICAN PSYCHOLOGICAL ASSOCIATION, INC.
PRINCE AND LEMON STS., LANCASTER, PA.
AND 1515 MASSACHUSETTS AVE., N. W., WASHINGTON 5, D. C.

Entered as second-class matter, February 6, 1937, at the post office at Lancaster, Pa., under the Act of March 3, 1879
Acceptance for mailing at the special rate of postage provided for in paragraph (d-2), Section 34.40, P. L. & R. of 1948, authorized September 11, 1947.

LANCASTER PRESS, INC., LANCASTER, PA.

CONTENTS OF VOLUME 42

AMMONS, CAROL H., AND WEITZ, J. **Central and Peripheral Factors in the Phi Phenomenon** 327

ANTONITIS, J. J. **Response Variability in the White Rat During Conditioning, Extinction, and Reconditioning** 273

ARCHER, E. J., AND UNDERWOOD, B. J. **Retroactive Inhibition of Verbal Associations as a Multiple Function of Temporal Point of Interpolation and Degree of Interpolated Learning** 283

BARKER, S. See PRENTICE, W. C. H.

BARLOW, J. A. See TURNER, R. H.

BATTERSBY, W. S. **The Regional Gradient of Critical Flicker Frequency After Frontal or Occipital Lobe Injury** 59

BATTERSBY, W. S., BENDER, M. B., AND TEUBER, H. L. **Effects of Total Light Flux on Critical Flicker Frequency after Frontal Lobe Lesion** 135

BENDER, M. B. See BATTERSBY, W. S.

BOYNTON, R. M., AND ROSS, L. A. **The Effect of Stimulus Area and Intensity upon the Human Retinal Response** 217

BRANTLEY, J. J. See SIEGEL, P. S.

BRICKER, P. D. See ROSS, S.

BRIGGS, G. E. See WICKENS, D. D.

BROGDEN, W. J., AND GREGG, L. W. **Studies of Sensory Conditioning Measured by the Facilitation of Auditory Acuity** 384

BULLOCK, D. H. **Operant Extinction as a Function of the Extinction Schedule** 437

CARPENTER, J. A. See DEESE, J.

CHANDLER, K. A. See WAPNER, S.

CHANDLER, K. A. See WERNER, H.

CHRISTIE, R. **The Role of Drive Discrimination in Learning Under Irrelevant Motivation** 13

CRUTCHFIELD, R. S. See EDWARDS, W.

DAVIS, R. C. See FINK, J. B.

DEESE, J., AND CARPENTER, J. A. **Drive Level and Reinforcement** 236

DUNCAN, C. P. **The Effect of Unequal Amounts of Practice on Motor Learning Before and After Rest** 257

EDWARDS, W., AND CRUTCHFIELD, R. S. **Differential Reduction of Autokinetic Movement by a Fixated Figure** 25

FEHRER, ELIZABETH. **Latent Learning in the Sophisticated Rat** 409

FERSTER, C. B. **The Effect on Extinction Responding of Stimuli Continuously Present During Conditioning** 443

FINK, J. B., AND DAVIS, R. C. **Generalization of a Muscle Action Potential Response to Tonal Duration** 403

FOX, B. H. **Figural After-Effects: "Satiation" and Adaptation** 317

GARNER, W. R. See HAKE, H. W.

GOAD, D. See UNDERWOOD, B. J.

GOSS, A. E. See ROSSMAN, IRMA L.

GRAHAM, C. H. See RATOOSH, P.

GRANT, D. A., AND HAKE, H. W. **Dark Adaptation and the Humphreys Random Reinforcement Phenomenon in Human Eyelid Conditioning** 417

GRANT, D. A., HAKE, H. W., AND HORNSETH, J. P. **Acquisition and Extinction of a Verbal Conditioned Response with Differing Percentages of Reinforcement** 1

GRAYBIEL, A., AND NIVEN, J. I. **The Effect of a Change in Direction of Resultant Force on Sound Localization: The Audiogravic Illusion** 227

GREGG, L. W. **Fractionation of Temporal Intervals** 307

GREGG, L. W. See BROGDEN, W. J.

GWINN, G. T. **Resistance to Extinction of Learned Fear-Drives** 6

HAKE, H. W., AND GARNER, W. R. **The Effect of Presenting Various Numbers of Discrete Steps on Scale Reading Accuracy** 358

HAKE, H. W. See GRANT, D. A.

HAKE, H. W. See RIOPELLE, A. J.

HARRIS, J. D., RAWNSLEY, ANITA I., AND KELSEY, PATRICIA. **Studies in Short-Duration Auditory Fatigue: I. Frequency Differences as a Function of Intensity** 430
HILGARD, E. R., JONES, L. V., AND KAPLAN, S. J. **Conditioned Discrimination as Related to Anxiety** 94
HORNSETH, J. P. See GRANT, D. A.
HOVLAND, C. I., AND KURTZ, K. H. **Experimental Studies in Rote-Learning Theory. IX. Influence of Work-Decrement Factors on Verbal Learning** 265
ITTELSON, W. H. See KILPATRICK, F. P.
JONES, L. V. See HILGARD, E. R.
KAPLAN, S. J. See HILGARD, E. R.
KARLIN, L. **The Influence of Equality Judgments on the Constant Error** 300
KELSEY, PATRICIA. See HARRIS, J. D.
KILPATRICK, F. P., AND ITTELSON, W. H. **Three Demonstrations Involving the Visual Perception of Movement** 394
KOGAN, L. S. **Interference in Maze Learning as a Factorial Function of Similarity and Goal Gradient** 69
KRIMSKY, JOSEPHINE. See PRENTICE, W. C. H.
KURTZ, K. K. See HOVLAND, C. I.
LIBBY, A. **Two Variables in the Acquisition of Depressant Properties by a Stimulus** 100
LOGAN, F. A. **A Comparison of Avoidance and Nonavoidance Eyelid Conditioning** 390
LOZITO, C. C. See MISIAK, H.
MANN, C. W. **The Effects of Auditory-Vestibular Nerve Pathology on Space Perception** .. 450
MARKS, M. R., AND RAMOND, C. K. **A New Technique for Observing Concept Evocation** 424
MARKS, M. R. See WORCHEL, P.
MISIAK, H., AND LOZITO, C. C. **Latency and Duration of Monocular and Binocular After Images** 247
MONTGOMERY, K. C. **"Spontaneous Alternation" as a Function of Time between Trials and Amount of Work** 82
MORANT, R. B. See WAPNER, S.
MUENZINGER, K. F., AND POWLOSKI, R. F. **Motivation in Learning: X. Comparison of Electric Shock for Correct Turns in a Corrective and a Non-Corrective Situation** 118
NAGATY, M. O. **The Effect of Reinforcement on Closely Following S-R Connections: I. The Effect of a Backward Conditioning Procedure on the Extinction of Conditioned Avoidance** 239
NAGATY, M. O. **The Effect of Reinforcement on Closely Following S-R Connections: II. Effect of Food Reward Immediately Preceding Performance of an Instrumental Conditioned Response on Extinction of that Response** 333
NIVEN, J. I. See GRAYBIEL, A.
POSTMAN, L. **The Generalization Gradient in Recognition Memory** 231
POWLOSKI, R. F. See MUENZINGER, K. F.
PRENTICE, W. C. H., KRIMSKY, JOSEPHINE, AND BARKER, S. **The Roles of Pattern and Apparent Distance in Determining the Color of Areas Seen Through Transparencies** .. 201
RAMOND, C. K. See MARKS, M. R.
RATOOSH, P., AND GRAHAM, C. H. **Areal Effects in Foveal Brightness Discrimination** . 367
RAWNSLEY, ANITA I. See HARRIS, J. D.
RICHARDS, W. J. **The Effect of Alternating Views of the Test Object on Vernier and Stereoscopic Acuities** 376
RIGGS, L. A. See BOYNTON, R. M.
RIOPELLE, A. J., AND HAKE, H. W. **Area-Intensity Relations in Scotopic Vision Using Annular Stimuli** 54
ROSS, S., AND BRICKER, P. D. **The Effect of an Amount-Set on a Repetitive Motor Task** .. 39
ROSSMAN, IRMA L., AND GOSS, A. E. **The Acquired Distinctiveness of Cues: The Role of Discriminative Verbal Responses in Facilitating the Acquisition of Discriminative Motor Responses** 173
SIEGEL, P. S., AND BRANTLEY, J. J. **The Relationship of Emotionality to the Consummatory Response of Eating** 304
SMITH, W. M. **Sensitivity to Apparent Movement in Depth as a Function of "Property of Movement"** 143
SPENCE, K. W., AND TAYLOR, JANET. **Anxiety and Strength of the UCS as Determiners of the Amount of Eyelid Conditioning** 183

STONE, G. R. **The Effect of Negative Incentives in Serial Learning: V. Response Repetition as a Function of Successive Serial Verbal Punishments** 20
TAYLOR, JANET, See SPENCE, K. W.
TEUBER, H. L. See BATTERSBY, W. S.
THUNE, L. E. **Warm-up Effect as a Function of Level of Practice in Verbal Learning** 250
TURNER, R. H., AND BARLOW, J. A. **Memory for Pleasant and Unpleasant Experiences: Some Methodological Considerations** 189
UNDERWOOD, B. J. **Associative Transfer in Verbal Learning as a Function of Response Similarity and Degree of First-List Learning** 44
UNDERWOOD, B. J. **Studies of Distributed Practice: II. Learning and Retention of Paired-Adjective Lists with Two Levels of Intra-List Similarity** 153
UNDERWOOD, B. J. **Studies of Distributed Practice: III. The Influence of Stage of Practice in Serial Learning** 291
UNDERWOOD, B. J. See ARCHER, E. J.
UNDERWOOD, B. J., AND GOAD, D. **Studies of Distributed Practice: I. The Influence of Intra-List Similarity in Serial Learning** 125
UNDERWOOD, B. J., AND VITERNA, R. O. **Studies of Distributed Practice: IV. The Effect of Similarity and Rate of Presentation in Verbal-Discrimination Learning** 296
VAN KREVELEN, ALICE. **The Ability to Make Absolute Judgments of Pitch** 207
VITERNA, R. O. See UNDERWOOD, B. J.
WAPNER, S., WERNER, H., AND CHANDLER, K. A. **Experiments on Sensory-Tonic Field Theory of Perception: I. Effect of Extraneous Stimulation on the Visual Perception of Verticality** 341
WAPNER, S., WERNER, H., AND MORANT, R. B. **Experiments on Sensory-Tonic Field Theory of Perception: III. Effect of Body Rotation on the Visual Perception of Verticality** 351
WAPNER, S. See WERNER, H.
WASSERMAN, H. N. **The Effect of Motivation and Amount of Pre-Rest upon Inhibitory Potential in Motor Learning** 162
WEITZ, J. See AMMONS, CAROL H.
WERNER, H., WAPNER, S., AND CHANDLER, K. A. **Experiments on Sensory-Tonic Field Theory of Perception: II. Effect of Supported and Unsupported Tilt of the Body on the Visual Perception of Verticality** 346
WERNER, H. See WAPNER, S.
WICKENS, D. D., AND BRIGGS, G. E. **Mediated Stimulus Generalization as a Factor in Sensory Pre-Conditioning** 197
WORCHEL, P., AND MARKS, M. R. **The Effect of Sleep Prior to Learning** 313
YAMAGUCHI, H. G. **Drive (D) as a Function of Hours of Hunger (h)** 108
ZELLER, A. F. **An Experimental Analogue of Repression: III. The Effect of Induced Failure and Success on Memory Measured by Recall** 32

Journal of
Experimental Psychology

VOL. 42, NO. 6 DECEMBER, 1951

AREAL EFFECTS IN FOVEAL BRIGHTNESS DISCRIMINATION [1]

BY P. RATOOSH

The Ohio State University

AND

C. H. GRAHAM

Columbia University

If part of a uniformly lighted surface is changed in brightness, the smallest change that can be discerned depends on a number of variables, among which are the following: (a) the original brightness, I, of the lighted surface (**8, 9, 10, 12, 13**); (b) the duration of the change (**6, 11**); (c) the size of the region whose brightness is changed (**4, 5, 10, 14, 16**); and (d) the size of the original, or adapting, field. For any given set of the four conditions, the smallest change in brightness that can be detected is known as the difference threshold, ΔI_t.

Little work has been concerned with the fourth variable. The only study of brightness discrimination investigating the effects of systematic variations in both the size of the ΔI- (or test-) field and the size of the I-field is that of Graham and Veniar (**7**), who used concentric, centrally fixated, circular fields as stimuli. Graham and Veniar used five fields, of diameters .6°, 1.2°, 2.4°, 4.8°, and 9.6°; only the smallest two lay within the rod-free area. Beyond the fovea Graham and Veniar's data indicate that, for a given diameter of test-field, $D_{\Delta I}$, and a given adapting brightness, I, an increase in the diameter of the adapting-field, D_I, has no effect on $\Delta I_t/I$. In like manner, for a given D_I and a given I, $\Delta I_t/I$ is little, if at all, changed by a change in $D_{\Delta I}$. For the fovea Graham and Veniar found that brightness discrimination is best with equally sized I- and ΔI-fields that approach the limits of the rod-free area of the retina.

The available data provide us with little basis for estimating the relations between $\Delta I_t/I$ and size of I-field, and $\Delta I_t/I$ and size of ΔI-field in the fovea.

[1] This account was prepared under Project NR 142-404; Contract N6onr-271, Task Order IX, between Columbia University and the Office of Naval Research, U. S. Navy. Professor Conrad G. Mueller contributed much helpful advice. Messrs. E. Davy, R. T. Brooke, and H. W. Leibowitz acted as *Ss*. Reproduction in whole or in part permitted for any purpose of the United States Government.

The purpose of the present report is to determine the nature of the foveal relationships more precisely.

Apparatus and Procedure

A schematic diagram of the apparatus is shown in Fig. 1. The apparatus is similar to that described by Baker (1). It is designed to provide S with a uniformly illuminated, circular field of light (I), to which may be added another circular field (ΔI), concentric to the first, .02 sec. in duration.

Two 150-w. incandescent lamps (S_1 and S_2), each placed behind a small aperture in a metal plate (A_1 and A_2), provide the illumination for the adapting (I) and testing (ΔI) beams. The lamps are operated at 115 v. DC. In both beams the light rays from the source are made parallel by lenses (L_1 and L_2) and are then brought to a focus by other lenses (L_3 and L_4) on a half-silvered mirror (M), which transmits part of the I-beam and reflects part of the ΔI-beam. From M both beams follow the same path to S's eye (O) through lenses L_5 and L_6.

Two field stops (F_2 and F_3) limit the visual fields provided by the I-beam and the ΔI-beam respectively. A sector disc shutter (E) run by a constant speed motor gives exposures of the ΔI-beam .02 sec. in duration. A relay-controlled mechanical stop enables E to present single exposures. A wedge (W) permits continuous variation of the brightness of the ΔI-beam. Brightness of the beams can also be controlled by fixed filters at D_1, D_2, and D_3.

The diameter of the ΔI-field, $D_{\Delta I}$, and of the I-field, D_I, ranged from .17 to 1.34 degrees of visual angle. An aperture stop (F_1), 2 mm. in diameter, at S's eye, serves as an artificial pupil.

Both beams were calibrated by a binocular match with a standard known source employing field and aperture stops respectively equal to those in the apparatus. By such a match the brightness of the I-beam was determined to be 8,000 millilamberts and the ΔI-beam 11,840 millilamberts.

First series of determinations.—In the first part of the experiment $\log \Delta I_t/I$ was investigated as a function of $\log I$, with $D_{\Delta I}$ and D_I as parameters. Each session consisted of the determination of $\Delta I_t/I$ with $D_{\Delta I}$ and D_I constant for six levels of illumination from .08 to 8,000 millilamberts or from $\bar{2}.903$ to 3.903 log millilamberts. The sizes of D_I and $D_{\Delta I}$ used were .17°, .34°, .67°, and 1.34° visual angle. In each session a different combination of D_I and $D_{\Delta I}$ was used. Since, for the condition that $D_{\Delta I}$ is never greater than D_I, there are ten possible combinations of the two fields, the first part of the experiment involved ten determinations of the relation of $\Delta I_t/I$ to I for each S in ten different sessions.

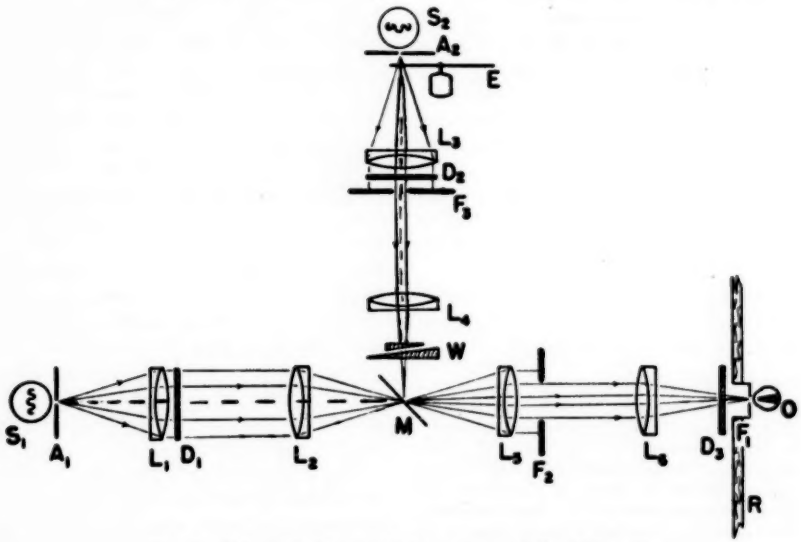

Fig. 1. Schematic diagram of the apparatus (after Baker, 1)

Second series.—After the data of the first series were collected for two Ss, B and D, it was felt that more would be shown about the precise nature of the relation between brightness discrimination and the size of the two fields if more values of $D_{\Delta I}$ and D_I were used. Accordingly the experiment was repeated with subject D with the addition of two values of $D_{\Delta I}$ and D_I—.50° and 1.00° visual angle. The procedure for this repetition was modified so that all the data for a given adapting illumination and given D_I (with a single exception[2]) were obtained in one session; it was presumed that this procedure would minimize the effect of day-to-day variability in the difference threshold. Thus, in 21 experimental sessions $\log \Delta I_i/I$ was investigated as a function of $D_{\Delta I}$ with $\log I$ and D_I as parameters. If time permitted, more than one D_I was investigated in a single session. Five levels of illumination, from $\bar{2}.903$ to 2.903 log millilamberts, were studied in this part of the experiment.

Third series.—In a separate experiment additional data were collected for the following conditions: $D_{\Delta I} = .67°$, $D_I = .67°$, $D_I = 1.34°$, and $\log I = \bar{1}.903$ millilamberts for subject B; and $D_{\Delta I} = .34°$ and .67°, $D_I = .34°$, .67°, and 1.34°, and $\log I = \bar{1}.903$ millilamberts for subject L.

In each series *S* was dark adapted for 10 min. before each session and was then light adapted for 5 min. to the first brightness and area to be employed. The *S* was instructed to fixate on the center of the circular *I*-field throughout the experiment. Each *S* used his left eye.

The method of limits was employed in the determination of ΔI_i at given values of I, D_I and $D_{\Delta I}$ with alternate ascending and descending series. In an ascending series ΔI was increased in steps of .05 log unit until *S* reported seeing the flash. In a descending series ΔI was decreased in the same intervals until *S* reported that he did not see it.

Presentations were made at the rate of one every 10 sec. Five ascending and five descending series were given at each set of conditions of I, $D_{\Delta I}$, and D_I in the first part of the experiment and in the additional sessions, and three ascending and three descending series were given in the second part.

When a change was made in the level of illumination in the first part of the experiment or in D_I in the second part, 3 min. of light adaptation to the new condition were given *S*. All changes in illumination were from lower to higher; all changes in D_I were from smaller to larger.

[2] $\Delta I_i/I$ for the first three $D_{\Delta I}$ values (for $D_I = 1.34°$ and $\log I = 2.903$) was determined on a different day from the last three.

Results

First series.—The data of the first part of the experiment[3] (in which $D_{\Delta I}$ and D_I are parameters) are presented in Fig. 2, which gives a graph of the average data. (The ordering of curve positions is similar for the data of the two Ss). $\text{Log } \Delta I_i/I$ values are plotted as a function of $\log I$, each curve representing a different combination of sizes of test- and adapting-field.

Figure 2 shows that $\log \Delta I_i/I$ falls rapidly at low brightnesses, levels off at high values of I, and in some of the curves shows a final rise. This result is similar to the one obtained by Koenig and Brodhun (**12, 13**). Steinhardt (**16**) found that the rising part of the curve is suppressed somewhat by the use of a large adapting-field. In this experiment no adapting-field approached the size of that used by Steinhardt since all the adapting-fields employed were foveal. Why no functional relation is revealed between the size of the adapting-fields and the extent of the rise is not clear, but it is probably related to the fact that since $D_{\Delta I}$ is almost as large as D_I for all the curves, the adapting-field is in no case large enough in comparison with the test-field to be effective in suppressing the rise. Since all the test-fields of the experiment stimulated the rod-free area of the retina, none of the curves evidences a rod portion.

For all but the lowest values of I, Fig. 2A, 2B, and 2C show that, for a given $D_{\Delta I}$, brightness discrimination

[3] For the numerical data of the experiment, order Document 3251 from the American Documentation Institute, 1719 N St. N. W., Washington 6, D. C., remitting $1.00 for microfilm (images 1 inch high in standard 35-mm. motion picture film) or $1.00 for photocopies (6 × 8 in.) readable without optical aid. The data of Fig. 2 and 3 are given in tabular form for the different *S*s. Table I of the document relates to Fig. 2; Table II, to Fig. 3.

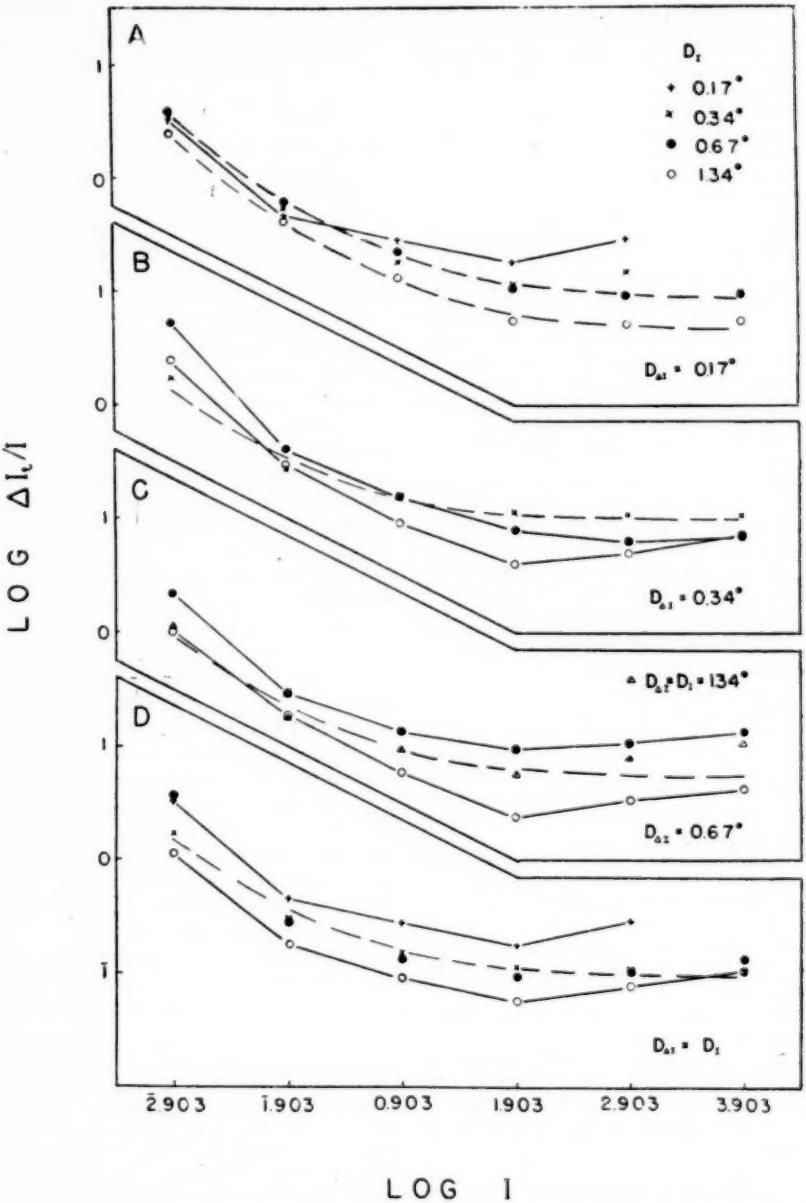

FIG. 2. Log $\Delta I_t/I$ as a function of log I for various sizes of test- and adapting-fields. Data are averaged for two *Ss*. The dashed lines represent Hecht's (8) brightness discrimination curve for the cones.

is better with large adapting-fields. In Fig. 2A and 2B the curves for the two smallest adapting-fields intersect the others. In Fig. 2A the curve for $D_I = .17°$ crosses the two D_I curves just larger at a brightness between 1.903 and .903 log millilambert, and the curve for $D_I = .34°$ crosses the next larger D_I at a brightness between .903 and 1.903 log millilambert. In Fig. 2B the curve for $D_I = .34°$ crosses the next larger D_I curve at about .903 log millilambert. These graphs show that the size of the adapting-field influences the steepness of the curves: the smaller D_I, the shallower the curve.

The triangles in Fig. 2C represent the condition of $D_{\Delta I} = D_I = 1.34°$. This curve lies almost completely above the curve for $D_{\Delta I} = .67°$ in Fig. 2C. Similarly, for the three highest brightnesses $\log \Delta I_t/I$ is smaller for the condition $D_{\Delta I} = .34°$ and $D_I = .67°$ than for the condition $D_{\Delta I} = D_I = .67°$. This is not the case, however, for the three lowest brightnesses.

Figure 2D presents all the data for the first part of the experiment for the condition $D_{\Delta I} = D_I$. For all but the lowest brightness these curves show that the greater the areas used, the smaller $\Delta I_t/I$ becomes. These results are precisely those of Graham and Bartlett (3) who, however, did not obtain a final rise in the curves presumably because their maximum brightness was not great (log millilamberts = 2.74; log photons = 4.11).

Second series.—The data of the second part of the experiment are presented in Fig. 3. It will be remembered that the procedure of this experiment was such that all the data for a given adapting brightness and a given D_I (with the exception mentioned above) were obtained in one session in order to minimize the effect of day-to-day variability in the difference threshold. The data of this section of the experiment show that (a) for a given adapting-field size, increasing the size of a very small test-field lowers $\Delta I_t/I$; (b) for a moderately large test-field an increase in size has little effect on $\Delta I_t/I$; and (c) for a test-field almost as large as its adapting-field, an increase in size up to the limits of the adapting-field may result in increases in $\Delta I_t/I$, especially at high adapting-field brightnesses. The analysis that leads to these conclusions is made by means of Fig. 3 and a comparison of this figure with the data of Fig. 2 (data of the first series).

Figure 3, in which $\log \Delta I_t/I$ is plotted as a function of $D_{\Delta I}$, presents the curves for all but the two smallest values of D_I. (At the next to the smallest value of D_I, .34°, the curve would consist for each value of $\log I$ of only two points; at the smallest value, .17°, of only one. See legend for Fig. 3.)

It may be seen in any single curve that, for small values of $D_{\Delta I}$, $\log \Delta I_t/I$ becomes smaller as $D_{\Delta I}$ increases. The curves representing the largest values of D_I (closed and open circles) tend to rise at a point just before $D_{\Delta I}$ becomes equal to D_I. The data of Fig. 2, from the first part of the experiment, lead one to expect a rise for the high brightnesses but not for the low ones. The largest adapting field in Fig. 2 shows an appreciable rise in $\log \Delta I_t/I$ as $D_{\Delta I}$ increases only for the two highest brightnesses. In Fig. 2 there are probably too few values of $D_{\Delta I}$ to show this effect for the D_I of .67°. In Fig. 2C the relationship between the curves for the conditions $D_{\Delta I} = .67°$, $D_I = 1.34°$ (open circles) and $D_{\Delta I} = D_I = 1.34°$ (triangles) show that a rise in the curves of Fig. 3 for these conditions is consistent with a rise at all but the two lowest

brightnesses. As shown in Fig. 3, although the rise is not a monotonic function of brightness, the rise for these latter conditions (open circles for .67° and 1.34°) is least pronounced for the two lowest brightnesses.

The curves in Fig. 3 representing a D_I of .50° (x's) show the rise only at the highest brightnesses. At the two lowest brightnesses they decline, and at the middle brightness the curve shows a slight rise. This result cannot be compared with data of the first part of the experiment because, as has been mentioned, the first part of the experiment involves too few data at comparable values of D_I.

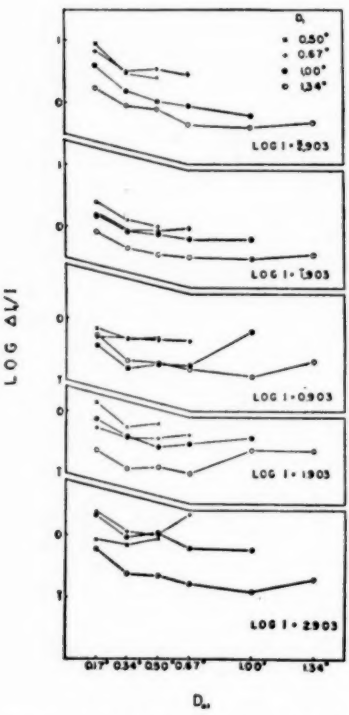

FIG. 3. Log $\Delta I_i/I$ as a function of $D_{\Delta I}$ for various values of D_I and I. Data are for subject D. Data are not presented for D_I = .17 and .34. For D_I = .17 and $D_{\Delta I}$ = .17, the log $\Delta I_i/I$ values are (for the five successively increasing values of log I) .878, .578, 1.103, .537, and .120. For D_I = .34 and $D_{\Delta I}$ = .34, the corresponding log $\Delta I_i/I$ values are .873, .070, −.005, −.313, and .137. For D_I = .34 and $D_{\Delta I}$ = .17, the values are: .895, .362, .045, −.305, and −.030. See footnote 3.

Figure 3 also shows the relationship between $\Delta I_i/I$ and D_I. For a given I and a given $D_{\Delta I}$, $\Delta I_i/I$ becomes smaller as D_I increases, as was shown in and discussed in connection with Fig. 2. The regularity of this change might be expected to be somewhat lessened by day-to-day variability in the difference threshold, so that little can be said precisely about the influence of changes in D_I on brightness discrimination. In Fig. 2 it may be seen that the order of magnitude of the effect of changes in D_I is much smaller than changes in the curves with variations in brightness.

Third series.—As a further investigation of the nature of the effect of a change in adapting-field size we performed an extra experiment at a single brightness. In this experiment D_I was varied in a single session, and more determinations were made at each value than in the second series. The data for these extra sessions are given in Table I. These data confirm the findings of the other experiments: for a given $D_{\Delta I}$, brightness discrimination is best with large adapting-fields. One discrepancy may be noted between these data and the findings of the second series. The values in the second series of log $\Delta I_i/I$ for log $I = \bar{1}.903$ for the two conditions, $D_{\Delta I} = D_I = .34°$ and $D_{\Delta I} = .34°$, $D_I = .67°$, are very close (.070 and −.072 respectively). The values in Table I of log $\Delta I_i/I$ for these conditions differ by a greater amount and in the opposite direction. The data of the first series for these conditions are in agreement with the values of the second series.

TABLE I

LOG $\Delta I_t/I$ FOR VARIOUS DIAMETERS OF TEST- AND ADAPTING-FIELD

Log $I = \bar{1}.903$ millilamberts. Each log $\Delta I_t/I$ value is the average of 10 determinations. Field diameter in degrees visual angle.

S	$D_{\Delta I}$	D_I	Log $\Delta I_t/I$
L	.34	0.34	−.275
	.34	0.67	−.425
	.34	1.34	−.440
	.67	0.67	−.670
	.67	1.34	−.760
B	.67	0.67	−.525
	.67	1.34	−.575

In summary: the data of the second and third parts of the experiment indicate that (a) for a given adapting-field size, increasing the size of a very small test-field lowers $\Delta I_t/I$; (b) for a moderately large test-field, an increase in size has little effect on $\Delta I_t/I$; and (c) for a test-field almost as large as its adapting-field, an increase in size up to the limits of the adapting-field may result in increases in $\Delta I_t/I$, especially at high adapting-field brightnesses.

DISCUSSION

The dashed lines in Fig. 2 are Hecht's (5) brightness discrimination curve for the cones, $\Delta I_t/I = c\ (1 + (KI)^{-1})^2$, where c and K are constants. It is clear that Hecht's curve does not fit all the data. In particular it cannot fit any set of points showing a rise at high brightnesses. Keller (11) has demonstrated that a rise is usually obtained when the duration of ΔI is above the critical duration and is not obtained when the duration of ΔI is below the critical duration. With durations of ΔI far greater than the critical duration Steinhardt (16) found a rise in the curve with very small test-areas. The present results indicate that even with durations of ΔI below the critical duration a rise in the curve is usually obtained when the adapting-field is not larger than the rod-free area of the fovea.

With respect to the effects of area, two findings emerge from the results: (a) for a given brightness and constant test-field size, brightness discrimination improves as the size of the adapting-area increases; and (b) for a given brightness and constant adapting-field area, brightness discrimination improves as the size of the test-field increases until an optimal size of test-field is attained; beyond this size, an increase in the size of the test-field may result in higher values of $\Delta I_t/I$.

To rationalize our results, it seems necessary to postulate that interaction processes take place between the retinal I-field and the associated $(I + \Delta I)$ field. The improved brightness discrimination with large surrounds implies that a retinal area is made more sensitive, with regard to brightness discrimination, by an adjacent illuminated field.

Beitel (2) obtained a similar result for absolute threshold. He found that the threshold for a small, foveal region was diminished by the presence of a nearby area when the brightness of the latter was of the same order of magnitude as the threshold of the former. This effect increases as the separation decreases. A like effect has been obtained in flicker by Creed and Ruch (3). These investigators observed that the critical fusion frequency of a small, foveal field is raised when a large illuminated area is made to surround the flickering field.

The results of Beitel, Creed and Ruch, and the present results may be formally described in terms of the neural activity in the cones stimulated. Consider two points in a foveal region stimulated by a small

uniform field at low brightness. It is assumed that a small increase in retinal illumination at one of the points has two effects: it increases the activity at the point illuminated, and decreases the activity at the nearby point, this decrease becoming smaller as the distance between the points increases.

The proposed interaction hypothesis may be explicitly stated and the concept, activity, formally defined as follows:

1. For a threshold (absolute or difference) discrimination, the difference between the activity, A, in that part of the retina stimulated by the test-field before ΔI is presented and the activity in the same region when ΔI is presented is constant.

2. The activity, A, in a retinal region is a negatively accelerated, monotonically increasing function of the illumination of that region.

3. The activity in the retinal test-field region before ΔI is presented is a monotonically decreasing function of the size of the illuminated region surrounding it. [In the present experiment, other conditions being constant, $A = f_1 (D_I - D_{\Delta I})$.]

Assumptions 1 and 2 imply that ΔI_t is a monotonically increasing function of I. Thus, if I is increased by a constant amount, the resulting increase in activity will depend on the absolute value of I, being smaller for large I. Therefore, for a constant difference in activity, a greater ΔI will be required at high values of I. This conclusion is clearly in accord with all of the data of brightness discrimination.

Assumptions 1 and 3 lead to the result that brightness discrimination improves when the size of the adapting-field is increased. Assumption 3 states that the activity in the test-field region before ΔI is presented will be smaller with large D_I. Therefore, ΔI_t will be smaller, the larger D_I. These two assumptions also predict Beitel's finding that the threshold for a small, foveal field is reduced by the presence of a dim nearby area. The results of Creed and Ruch, that a surround for a foveal flickering field raises the critical fusion frequency, are also described by Assumptions 1 and 3 if the detection of flicker is held to require a constant difference in activity between the light and dark phases.

That the curve relating log $\Delta I_t/I$ and $D_{\Delta I}$ attains a minimum at high brightnesses implies that the function relating activity and size of illuminated field is itself a function of the brightness of the field.

Nothing has been said in the above discussion about the influence on test-field activity of the brightness of the surround. To describe the data mentioned above, nothing need be said about the surround-illumination; however, the relationship between surround-brightness and test-field activity is of consequence in Beitel's second finding that threshold in one foveal region is increased if the brightness of another foveal region is increased beyond ten times the brightness of the first. Contrast phenomena indicate that this relationship is not a simple one—the change in activity of the test-field is influenced not by the brightness of the surround alone but by some function of both surround-brightness and test-field brightness.

The results of the present experiment for small values of $D_{\Delta I}$ in the fovea are not in accord with results reported by Graham and Veniar (7). These authors found that "intensity discrimination for a small, foveal ΔI-field is, over a large range of adapting intensities, better with no surround than it is with a small surround." Figure 2 shows that this result was not obtained by us. We do not here attempt to account for the discrepancy but feel considerable confidence in the more extensive data of the present experiment.

Summary

1. The effect on foveal brightness discrimination of changes in the diameters of the test- (ΔI-) and adapting- (I-) fields has been investigated.

2. An apparatus has been described designed to present to one eye of the *S* a foveal, circular illuminated I-field to which may be added a concentric, circular ΔI-field, smaller than or equal in size to the I-field. The ΔI-field was presented for a duration of .02 sec.

3. For constant sizes of test- and adapting-field, the curve relating log $\Delta I_t/I$ and log I falls rapidly at low values of log I; it then levels off at medium values of log I. At high values of log I, when the adapting-field is not larger than the rod-free area of the fovea, the curve usually shows a small final rise.

4. For a given brightness and constant test-field size, $\Delta I_t/I$ decreases as the size of the adapting field increases.

5. For a given brightness and constant adapting-field size, increasing the size of a very small test-field lowers $\Delta I_t/I$. For a moderately large test-field an increase in size has little effect on $\Delta I_t/I$. For a test-field almost as large as its adapting-field, an increase in size up to the limits of the adapting field may result in increases in $\Delta I_t/I$, especially at high adapting-field brightnesses.

6. The results are discussed in terms of a neural interaction hypothesis.

(Manuscript received January 20, 1951)

References

1. Baker, H. D. The course of foveal light adaptation measured by the threshold intensity increment. *J. Opt. Soc. Amer.*, 1949, **39**, 172–179.
2. Beitel, R. J., Jr. Inhibition of threshold excitation in the human eye. *J. gen. Psychol.*, 1936, **14**, 31–61.
3. Creed, R. A., and Ruch, T. C. Regional variations in sensitivity to flicker. *J. Physiol.*, 1932, **74**, 407–423.
4. Crozier, W. J., and Holway, A. H. Theory and measurement of visual mechanisms. III. ΔI as a function of area, intensity, and wave-length, for monocular and binocular stimulation. *J. gen. Physiol.*, 1939, **23**, 101–141.
5. Graham, C. H., and Bartlett, N. R. The relation of size of stimulus and intensity in the human eye: III. The influence of area on foveal intensity discrimination. *J. exp. Psychol.*, 1940, **27**, 149–159.
6. Graham, C. H., and Kemp, E. H. Brightness discrimination as a function of the duration of the increment in intensity. *J. gen. Physiol.*, 1938, **21**, 635–650.
7. Graham, C. H., and Veniar, F. A. The influence of size of test-field surround on visual intensity discrimination. *Proc. Nat. Acad. Sci.*, 1950, **36**, 17–25.
8. Hecht, S. A theory of visual intensity discrimination. *J. gen. Physiol.*, 1935, **18**, 767–789.
9. Hecht, S., Peskin, J. C., and Patt, M. Intensity discrimination in the human eye. II. The relation between $\Delta I/I$ and intensity for different parts of the spectrum. *J. gen. Physiol.*, 1938, **22**, 7–19.
10. Holway, A. H., and Hurvich, L. M. Visual differential sensitivity and retinal area. *Amer. J. Psychol.*, 1938, **51**, 687–694.
11. Keller, M. The relation between the critical duration and intensity in brightness discrimination. *J. exp. Psychol.*, 1941, **28**, 407–418.
12. Koenig, A., and Brodhun, E. Experimentelle Untersuchungen über die psychophysische Fundamentalformel in Bezug auf den Gesichtssinn. *Sitzber. K. Akad. Wiss., Ber.*, 1888, **2**, 917–931.
13. Koenig, A., and Brodhun, E. Experimentelle Untersuchungen über die psychophysische Fundamentalformel in Bezug auf den Gesichtssinn. Zweite Mittheilung. *Sitzber. K. Akad. Wiss., Ber.*, 1889, **2**, 641–644.
14. Lasareff, P. Studien über das Weber-Fechner'sche Gesetz. *Arch. ges. Physiol.*, 1911, **142**, 233–240.
15. Polyak, S. L. *The retina.* Chicago: Univ. Chicago Press, 1941.
16. Steinhardt, J. Intensity discrimination in the human eye. I. The relation of $\Delta I/I$ to intensity. *J. gen. Physiol.*, 1936, **20**, 185–209.

THE EFFECT OF ALTERNATING VIEWS OF THE TEST OBJECT ON VERNIER AND STEREOSCOPIC ACUITIES [1]

BY WALTER J. RICHARDS

University of Arkansas

A perception of depth is obtained when slightly disparate points in the two eyes are stimulated. This cue of retinal disparity appears to be the one responsible for our most precise judgments of depth. Since retinal disparity is such an important cue to depth, we might learn more about the mechanism of depth perception by investigating the relation between vernier and stereoscopic acuities. Disparity obtained in a depth situation is similar to that obtained in a stereoscopic situation, when opposite lateral (vernier) displacements are presented to each eye. Stratton (6) was one of the first to suggest that the ability to perceive depth might be related to the ability to detect lateral displacements. More recently, Walls (7) proposed a method for testing the relation between vernier and stereoscopic acuities. Berry (3), who used a modification of the method proposed by Walls, tested the hypothesis that depth or stereoscopic acuity could be accounted for on the basis of perception of lateral displacements, one presented to each eye. Berry found that stereoscopic acuity remained unaccountably good under conditions which were unfavorable to the observation of lateral displacements.

The present experiment provides another line of attack upon the problem of the relation of stereoscopic to vernier acuity. The questions investigated were: (a) the effect of rate of alternation of stereoscopic and pseudoscopic views of the test object on the threshold for depth displacement; and (b) the effect of rate of alternation of right and left eye views of the test object on the threshold for lateral displacement. The visual fields, subjects, targets, and the experimental procedures were similar for the vernier and the depth conditions.

[1] This is a portion of a dissertation submitted to the Graduate School, Brown University in partial fulfillment of the requirements for the Ph.D. degree. The author is greatly indebted to Prof. Lorrin A. Riggs who provided invaluable guidance during the course of the research.

Apparatus

The floor plan of the apparatus is shown in Fig. 1. The *S* was seated in chair *O*, and his forehead rested in a stereoscope hood which was attached to the viewing tube *T*. This illuminated tube was fastened to table *A*, and it served to maintain a constant state of light adaptation in *S*. *X* on tables *B* and *C* marks the location of the center or variable rod of each target when it was in the zero displacement position. Each of the fixed rods of the target was 4,622 mm. from a line connecting the centers of the two eyes of *S*. Prisms were placed so the right eye viewed the target on table *C*, and the left eye viewed the one on table *B*. A_s, B_s, and C_s represent opaque screens which extended from floor to ceiling. These had apertures cut in them so as to expose the visual fields.

A white field (S_1) was placed at a distance of 450 mm. in front of each target, and the targets were seen against a white background (S_2). The brightnesses of these fields were matched visually, and were at a level of 85 millilamberts. A rectangular opening was cut in each front field (S_1) so as to expose the target. This aperture had a visual angle of 41′58″ in the vertical dimension and 53′11″ in the horizontal dimension. Directly behind each aperture was a mirror (*m*) placed at an angle of 45° to the median plane. When the mirror was in this position, *S* saw a white field (S_3) containing a pair of black fixation dots. These dots were placed so as to coincide with the position of the upper and lower ends of the variable rod of the target. The mirror was pivoted so it could be swung entirely out of the visual field, thus serving as a shutter for exposing

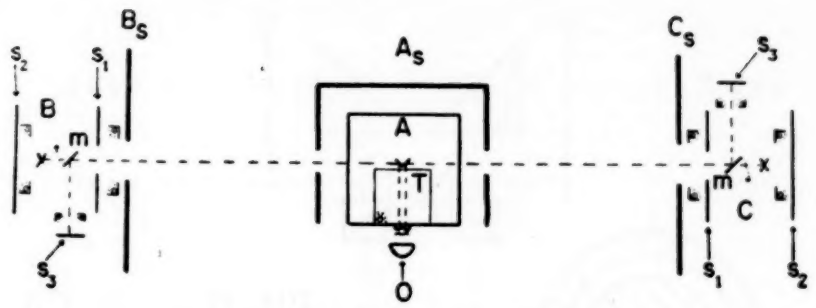

FIG. 1. Floor plan of the apparatus, not drawn to scale

the target. The solenoids which operated the mirrors were wired in parallel so the two targets were exposed simultaneously.

Each target consisted of three pieces of drill rod 10 cm. long and 2.4 mm. in diameter. They appeared to *S* as black vertical lines, each having a thickness of 107″ in visual angle. The previously mentioned rectangular opening in the visual field exposed a length of the rods of 42′ of visual angle. The fixed rods were in the same frontal plane, and were separated from one another by a horizontal distance of 21 mm., or 15′45″ of visual angle. The center rod of the target, mounted on a micrometer-driven slide, was variable in depth with respect to the plane of the fixed rods. The slide, taken from the cross slide of a Delta lathe, was driven by a gear and pulley system. Pulleys were connected to the targets in such a way that when one target was displaced, the other target was displaced by an equal amount in the same direction. Settings of the variable rod were recorded on an odometer-type counter which allowed readings of the rod position to a least count of .005 in.

A system of prisms and vanes was used to present alternate views of the targets to *S*. The prisms were mounted so they were not in direct contact with any other part of the apparatus. Figure 2 shows a diagram of the prism arrangement, one of the vanes, and views of the targets as they appeared when the vanes rotated. The prisms were placed in such a way that either of two light paths (view *R* or view *L*) could be directed into each eye. Sectors were cut from the vanes so that one light path was exposed while the other was covered. The vanes were driven by a series-wound motor the rate of which was controlled by a rheostat. Rates of rotation of the vanes were determined by means of a tachometer, the indicator of which was placed so it could be read by *E*.

Figure 2A shows the vane for the left eye, and the openings in the vane which allowed the passage of light for views *R* and *L* (*a* and *b* respectively). In the vane for the right eye these openings had the converse effect with respect to views *R* and *L*.

Figure 2B shows the arrangement of prisms and vanes, and the light paths for views *R* and *L*. For the left eye, view *L* is obtained when the vane allows light from the target to be totally reflected from two of the faces of prism *2* and from the half-silvered face of beam-splitter *3*. View *R* is obtained when the vane allows light from the target to be totally reflected by prism *1* through beam-splitter *3*. As the vane rotates, one view is presented while the other is cut off. A converse arrangement is shown for the right eye. *a* and *b* in Fig. 2B represent the positions of the vanes.

It becomes difficult to discuss alternating views of the targets when we refer both to the eyes of *S* and to the views which appear to come from the normal positions of the right and left eyes. For this reason, the view which is normally seen from the position of the right eye is designated as view *R*. The corresponding view from the normal position of a left eye is designated as view *L*. Figure 2C represents *R* and *L* views when the variable rod is before the plane of the fixed rods.

Figure 3 shows the views of the targets as they were presented in the depth and vernier conditions. *A* and *B* in this figure indicate the alternate views presented when *S* made a depth judgment. The bars represent the view presented to each eye, e.g., in *A* the center rod was displaced to the right for the right eye, while for the left eye it was displaced to the left. The lower figure under *A* shows the result of the fusion of the right and left eye views of the targets, namely, that the center rod was seen behind the plane of the fixed rods. This pseudoscopic view alternated with the one shown in *B*. The view

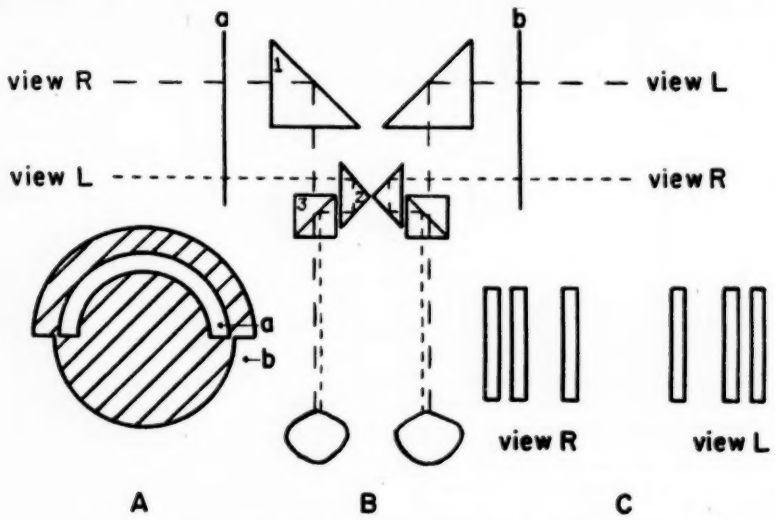

FIG. 2. Diagram of the prism arrangement, one of the vanes, and the targets as they appeared with view *R* and view *L*

in *B* is the same as the one in *A* except that the views were interchanged for the two eyes, and the center rod now appeared in front of the plane of the fixed rods (stereoscopic view). Thus, for each complete cycle of alternation of the vanes, the center rod appeared to be displaced first before and then behind the plane of the fixed rods.

C and *D* in Fig. 3 show the targets as they appeared to the right and left eyes when a vernier judgment was made. The center rod was first seen displaced to the left by both eyes, then to the right by both eyes. These views continued to alternate, and the center rod was seen displaced laterally but not in depth. The fused view for either *C* or *D* was the same as the view for either eye alone. Thus, for each complete cycle of alternation of the vanes, the center rod appeared to be displaced first to the right and then to the left.

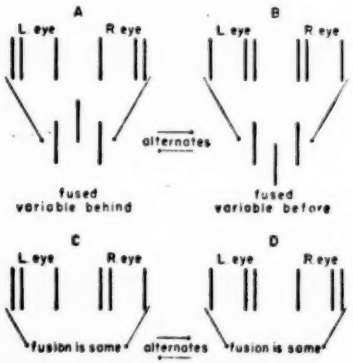

FIG. 3. Apparent target displacement as the views alternated for the depth and vernier situations

PROCEDURE

Subjects.—Three persons with normal vision served as *S*s. Two of the observers (RMB and LAR) had previous experience in making psychophysical judgments. The third observer (RB) had no previous experience.

Experimental design.—Ten days of preliminary training, equally divided between the vernier and depth conditions, was given to all *S*s. During this time the range of rates to be used for the two kinds of discrimination was determined. Five rates of rotation of the vanes were chosen for the vernier condition, and five for the depth conditions. These rates were .47, .94, 1.4, 1.8, and 2.3 cy./sec. for the depth condition, and .47, .94, 1.4, 7.5, and 12.5 cy./sec. for the vernier condition. Each cycle of alternation of the vanes presented one *R* and one *L* view of the targets to each eye. The ten conditions (five

rates for depth and five for vernier judgments) were randomized and counterbalanced.

The maximum rate at which depth discrimination was possible was determined after thresholds for the five rates common to all *Ss* had been measured. It was determined in the following manner. The rate was increased to the point where *S* could no longer give sufficiently consistent judgments to allow a threshold to be computed. Fifty settings of the stimulus were then presented, and the type of judgment made for each setting was recorded. At these high rates, *Ss* gave judgments of stereo, vernier, mixed "stereo-vernier," or no movement. "Stereo-vernier" judgments were recorded when *S* reported both lateral and depth movements simultaneously. In this case, the variable rod appeared to execute various elliptical movements as the views alternated. At still higher rates stereoscopic discrimination was altogether lost.

Method.—The method of constant stimuli with two categories of judgment was used. The vanes were put in rotation at the proper rate. A signal to fixate was given, then 1 sec. later the mirror shutters were opened to expose the targets. The targets were in view for a period of 4 sec. The *S* was required to report any displacement of the variable rod of the target as the vanes rotated. He was to report displacement in depth in the stereoscopic-pseudoscopic condition, and lateral displacement in the vernier condition.

During a 1-hr. session on each day *S* gave 20 judgments at each of five positions of the variable rod for a given rate of rotation of the vanes. Each rate for each condition (depth or vernier) was presented twice in a counterbalanced order The stimuli were presented in a prearranged. order, and rest periods were allowed during the series of judgments. Rest periods of 1 min. each were given after Judgment 15, 32, 65, and 82, and a rest of 5 min. was given after Judgment 50.

During preliminary training it was found that the *Ss* experienced difficulty in establishing a criterion for the required judgments. Consequently, the instructions were read before each experimental session. The point was emphasized that *S* must base his judgment on alternations in the position of the variable rod, rather than on a constant offset alone. He was told to give a positive report only when the variable rod appeared alternately to the right and to the left (vernier condition) or alternately before and behind (depth condition) with respect to the fixed rods.

Computation.—The threshold was considered to be the just discriminable distance of the variable rod from the zero displacement position. A combination of the normal interpolation and graphic methods was used to determine the threshold. The percentage of plus judgments for each of the five displacement values was converted to a z-score. The z-scores were plotted on linear graph paper as a function of the displacement of the variable rod from the zero position. A straight line was fitted to the data by the method of averages. The displacement corresponding to the 50 percent point was determined graphically, and this, converted to seconds of arc, was used as a measure of the threshold.

Results

The performances of the individual *Ss* under the vernier and depth conditions are shown in Fig. 4. The plotted points in this figure are mean threshold values. Each point is the mean of two determinations of the threshold at the given rate of rotation of the vanes.

It is apparent from the results shown that the stereoscopic threshold for all

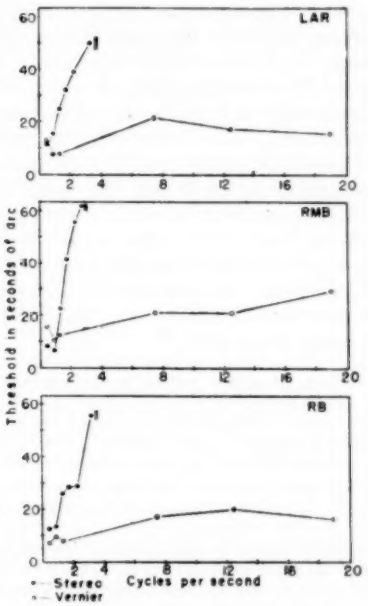

Fig. 4. Mean vernier and depth thresholds for three *Ss*

Ss rises rapidly as the rate of rotation of the vanes increases. Stereoscopic discrimination virtually disappears at rates of rotation above 3.2 complete cycles of alternation per second. A double line has been drawn after the final point on the stereoscopic curve in each graph to indicate that no threshold could be determined at higher rates of alternation.

Vernier thresholds have approximately the same values as stereoscopic ones at the lower rates of rotation. However, the vernier thresholds exhibit a much smaller rise than do the stereoscopic as rate of rotation is increased. A comparison of the thresholds obtained at the highest rate used for the stereoscopic condition (about three complete alternations per second) shows that the stereoscopic threshold is about five times the vernier at that rate.

The highest rate shown on the graphs did not represent the upper limit for vernier discrimination. It was the maximum rate at which the apparatus could be kept in continuous operation. Brief trials at higher rates showed that *Ss* could still make vernier judgments on the basis of alternating views at rates in excess of 20 cy./sec. The true upper limit was not of primary significance in this experiment, since the limit of stereoscopic discrimination was reached at a much lower rate.

While the general impression of these results is one of uniformity from one *S* to another, certain minor differences may be noted. Subject RMB, for example, shows particularly low stereoscopic thresholds at the lower rates of rotation. His vernier thresholds, however, are somewhat higher than those of the other *Ss*, especially at the highest rotation rate. His stereoscopic threshold rises more rapidly as the rate increases than does the threshold for the other two *Ss*. The limit for stereoscopic or depth discrimination is reached at a lower rate for this *S* than for the other two.

The results for the other two *Ss* (LAR and RB) are quite similar for both stereoscopic and vernier conditions.

All the curves show that the stereoscopic threshold rises abruptly as the rate of rotation of the vanes increases. With respect to threshold values, the *Ss* are more alike at the lower rates than at the higher ones. Differences between subjects increase as the rotation rate increases.

Discussion

The preceding results have shown that depth discrimination is affected much more by increase in the rate of alternation of the views than is vernier discrimination. Stereoscopic thresholds rose rapidly as rate increased. Vernier thresholds rose more slowly, and within the limits of this experiment, the increase was smaller than for the stereoscopic threshold. The neural mechanism for stereoscopic discrimination may well involve higher centers in the cortex. By contrast, vernier discrimination may be less dependent upon connections within the cortex. It is realized that in making this statement we are not explaining the findings. If the statement is true, more problems are created than are solved. Some of these problems are considered below.

The situations for stereoscopic and vernier discrimination were essentially the same, i.e., there was an alternation of views under both conditions. In the vernier situation, both eyes were presented with an *R* view, then an *L* view, and these alternated. The targets appeared as if they were being viewed first with one eye and then with the other. Since each eye received the same retinal image at any given time, presumably no cortical integration of the two retinal images would be required.

The stereoscopic situation differed from the vernier, since one eye received an *R* view at the same time the other eye received an *L* view. Thus, in the stereoscopic condition, each

eye received a different retinal image, so the two images would have to be integrated to give a perception of depth. More time may be required for the integration of different patterns from the two eyes in the stereoscopic situation than is required for the perception of a single pattern from the two eyes in the vernier situation. This supposition is supported by the fact that stereoscopic discrimination dropped out before vernier with an increase in the rate of alternation of the views.

It seems possible that vernier discrimination could occur on the basis of direct projection from retinal receptors, since it involves judgment of lateral displacement alone. The basis for this judgment could be the mosaic of the cone receptors.[2] Stereoscopic discrimination, on the other hand, could not be accounted for by an appeal to retinal processes. It seems to require the function of central structures in the visual system, since the views from the two eyes must be combined. Anatomically, the combination of views might occur at any one of three points: in the lateral geniculate body, in the superior colliculus, or in the optic cortex. According to Ranson and Clark (**5**), the first two structures function primarily in reflex activity. If this view is correct, it would support the commonly accepted belief that integration of patterns from the two eyes takes place in the cortex.

It is interesting that stereoscopic discrimination dropped out so much earlier than did vernier discrimination as the rate was increased. Undoubtedly vernier discrimination has a limiting rate of alternation, but this upper limit was not of primary importance for the present study and was not determined. One would predict, on the basis of the present results and from logical considerations, that the limit would be found near the critical fusion frequency (CFF). The present situation is similar to that used in CFF experiments, since the displacement of the dark target creates a light and dark period for the small retinal region affected by the target. Hecht and Smith (**4**) found that the CFF was near 30 flashes per second, when an area and intensity comparable to those employed in the present experiment were used. Thus, the highest rate used in the present study was approximately two-thirds the rate at which we might expect fusion.

It may be of interest to compare the results of the present study with those obtained from experiments on apparent movement. Most of the studies of apparent movement have been concerned with descriptions of perceptual phenomena, and few have attempted to measure thresholds. Wertheimer's results with respect to the time interval between stimuli required for a perception of apparent movement have been generally accepted (**8**, p. 682). It was found that the optimal time interval between stimuli for the pure phi movement was about 60 msec. When the interval between stimuli was less than 30 msec., the two stimuli were reported as appearing simultaneously. With intervals longer than 200 msec. between stimuli, *S*s reported that the stimuli were seen successively.

The only basis on which we can compare the results of the present study with those on apparent movement is with respect to the time interval between stimuli. This interval was very small in the present study.

[2] The fact that the receptors are discrete units need not prevent the perception of sharp and continuous contours. Andersen and Weymouth (**1**) have outlined a process by which the smoothing may take place at the peripheral level.

The two openings in each vane were cut so the ends were at different positions on a line drawn through the center of the vane. This design allowed one view of the targets to be covered at the same time the other view was exposed. Thus, the change from one view to the other was almost instantaneous. However, despite this short interval between stimuli, apparent movement of the variable rod was reported. For example, movement was reported when each view of the target lasted only 26 msec., so the interval between the two views was certainly much smaller.

The present study differs in another respect from the usual study of apparent movement. A series of stimuli was presented for each judgment. The number of alternate views of the targets varied with the rate of rotation of the vanes. The *S* received approximately two *R* and two *L* views at the slowest rate (.47 cy./sec.), 76 *R* and 76 *L* views at the highest vernier rate (19.0 cy./sec.), and 13 *R* and 13 *L* views at the highest stereoscopic rate (3.2 cy./sec.).

It is possible that the present results may have some relation to EEG data. It might be that the alpha rhythm is in some way responsible for the fact that stereoscopic thresholds could not be measured at rates of alternation higher than six changes per second. The next higher rate tested (seven changes per second), which was near the lower limit for the alpha rhythm, yielded no threshold. Bartley (**2**) found that retinal stimulation and the alpha rhythm could influence one another. In the present experiment, the stereoscopic stimulation might have caused impulses to arrive in the brain out of phase with the alpha rhythm, thus making stereoscopic discrimination impossible due to cancellation effects.

Summary and Conclusions

The present study investigated (a) the effect of rate of alternation of stereoscopic and pseudoscopic views of the targets on the threshold for depth, and (b) the effect of rate of alternation of *R* and *L* views of the targets on the vernier threshold.

A Helmholtz-type three-rod target was used. The outer rods were separated from one another by 21 mm., and were at a distance of 4,622 mm. from *S*. Alternate views of the targets were presented to each eye by means of a system of prisms and motor-driven vanes. Data were obtained from three *S*s by the method of constant stimuli with two categories of judgment. Each threshold was based upon 20 judgments at each of five stimulus positions.

Within the limits of the present experiment, the following conclusions may be drawn:

1. Stereoscopic discrimination falls off rapidly as the rate of alternation of views increases, while vernier discrimination is much less affected by increase in rate.

2. Stereoscopic discrimination is not possible at rates much above 4 cy./sec. alternation of the vanes.

3. Vernier discrimination is still possible at rates in excess of 20 cy./sec. alternation.

4. The stereoscopic threshold at the highest rate possible is about five times the vernier at the same rate.

5. It is suggested that some cortical process underlies stereoscopic discrimination, and that this mechanism cannot respond at rates higher than four alternations of the disparate views per second. In line with this suggestion, it may be recalled that data on reaction time show that central processes are of long duration. Also, electrical events (EEG's) in the

cortex have very long time characteristics.

(Manuscript received February 24, 1951)

References

1. Andersen, E. E., and Weymouth, F. W. Visual perception and the retinal mosaic. I. Retinal mean local sign—an explanation of the fineness of binocular perception of distance. *Amer. J. Physiol.*, 1923, **64**, 561–594.
2. Bartley, S. H. The relation between cortical response to visual stimulation and changes in the alpha rhythm. *J. exp. Psychol.*, 1940, **27**, 624–639.
3. Berry, R. N. Quantitative relations among vernier, real depth, and stereoscopic depth acuities. *J. exp. Psychol.*, 1948, **38**, 708–721.
4. Hecht, S., and Smith, E. L. Intermittent stimulation by light. VI. Area and the relation between critical frequency and intensity. *J. gen. Physiol.*, 1936, **19**, 979–989.
5. Ranson, S. W., and Clark, S. L. C. *The anatomy of the nervous system—its development and function.* Philadelphia: W. B. Saunders, 1947.
6. Stratton, G. M. Studies from the psychological laboratories of the University of California. I. A new determination of the minimum visible and its bearing on localization and binocular depth. *Psychol. Rev.*, 1900, **7**, 429–435.
7. Walls, G. L. Factors in human visual resolution. *J. opt. Soc. Amer.*, 1943, **33**, 487–505.
8. Woodworth, R. S. *Experimental psychology.* New York: Henry Holt, 1938.

STUDIES OF SENSORY CONDITIONING MEASURED BY THE FACILITATION OF AUDITORY ACUITY [1]

BY W. J. BROGDEN AND LEE W. GREGG

University of Wisconsin

This paper is a report of the results obtained in a series of six experiments on sensory conditioning measured as a facilitation of auditory acuity. All of these experiments are variations of the procedure already reported by Brogden (2).

In this initial study, *Ss* listened to ten trials of a 1,000-cycle tone that was approximately 15 db above absolute threshold. In the experimental group, the general illumination of the room was increased slightly during each of these trials. In the control group there was no change in illumination. All *Ss* were then told that their threshold would be measured and each was instructed to depress a telegraph key whenever he heard the tone. Thirty trials of the tone at the same intensity level as that used in the initial treatment were presented and this was followed by ten trials of the light (slight increase in the general illumination) interspersed in random sequence with ten additional trials of the tone. Finally, two absolute thresholds were obtained for each *S*. For one threshold, each presentation of the tone was accompanied by the light. For the other threshold, each presentation was of the tone alone.

The experimental and control groups could not be distinguished from each other in terms of frequency of response to the light, since only seven *Ss* responded at all (three in the experimental group and four in the control group) and none gave a frequency of response greater than two. However, the experimental and control groups did differ from each other in the difference in auditory acuity to the light and no-light conditions. Auditory acuity was 2.50 db greater under the light condition in the experimental group and .25 db greater under the light condition in the control group. The difference of 2.25 db between the differences was significant at better than the .05 level of confidence. Sensory conditioning, a relationship established between the tone and light during the ten trials of initial treatment received by *Ss* in the experimental group, was inferred from these results.

The six experiments to be reported in this paper were designed to answer questions that have their origin in the results just reviewed. Is the effect a function of the number of thresholds taken under the light and no-light conditions? Will the phenomenon show quantitative variation as a function of the number of sensory conditioning trials? Will there be the same effect if the light stimulus accompanying the tone is one of decrease in brightness? Does the size of the steps used in obtaining the auditory thresholds have any effect upon the phenomenon? Does the sequence in which the thresholds are taken for the light and no-light conditions have an effect upon the phenomenon?

These six experiments therefore differ from each other only in minor respects. The major difference between these six and the initial experiment is that four thresholds were taken under the light and no-light conditions immediately after the initial treatment of listening to the tone with or without the light.

Procedure

The experimental room and apparatus for the six experiments were the same as those described by Chernikoff and Brogden (3) and Brogden (2). The experiments were completed in the sequence designated by their numbers.[2] The source of the 1,000-cycle tone was two 2-in. loud speakers located under the table at the mid-point of which *S* was seated. Thus the tone was of indefinite localization. During the sensory conditioning trials the intensity of the tone was 28 db above 10—16 w./sq. cm. The light stimulus was pro-

[1] Supported in part by the Research Committee of the Graduate School from special funds voted by the State Legislature.

[2] Exp. I was completed entirely by Brogden. The *Ss* of the other experiments were run by both authors.

TABLE I

SUMMARY OF DIFFERENCES IN EXPERIMENTAL CONDITIONS

Exp.	Prethreshold Treatment		Light Stimulus	Sequence of Thresholds		Size of Steps in db
	Exp.	Control		Subgroup 1	Subgroup 2	
I	10T L	10T	increase	ABBAABBA	BAABBAAB	5
II	2T L	2T	increase	ABBAABBA	BAABBAAB	5
III	20T L	20T	increase	ABBAABBA	BAABBAAB	5
IV	10T L	10T	decrease	ABBAABBA	BAABBAAB	2
V	10T L	10T	increase	ABBAABBA	BAABBAAB	2
VI	10T L	10T	increase	AAAABBBB	BBBBAAAA	2

vided by a 20-w. fluorescent tube in a fixture attached to the ceiling behind the standard incandescent light fixture and directly behind *S*. The fluorescent tube was activated by a low voltage and thus produced part of the general illumination of the room. The light stimulus was produced by increasing the voltage applied to the fluorescent tube. The normal brightness of the mirror surface that *S* faced was 2.66 millilamberts. When the light stimulus was on, the brightness was 3.40 millilamberts. The difference of .74 millilamberts represents the brightness value of the light stimulus. The duration of the tone and light stimuli was 2 sec. in all cases.

The *Ss* were volunteers from classes in elementary psychology at the University of Wisconsin. The *N* for each experiment was 40, 20 *Ss* each in the experimental and control groups, except for Exp. VI in which there were 30 *Ss* each in the experimental and control groups. The *Ss* were assigned at random to the experimental or control groups and within these groups to subgroups for the two sequences of threshold determinations with and without light.

All *Ss* were given the same instructions. Each *S* was asked to listen to the tone that was to be used in measuring auditory acuity so that he would be familiar with it. If *S* did not indicate that he heard the tone on each trial, he was asked if he did. The *Ss* of the experimental group received light in combination with the tone; those in the control group were presented with the tone alone. When the listening trials had been completed, *E* instructed *S* to respond by depression of the telegraph key whenever he heard the tone. The *S* was told that he would not be able to hear all of the tones, but that he was to respond even if he was uncertain that he was hearing the tone. No mention was made of the light until after the experiment was over. The *S* was then asked if he was aware of the light, and if so, whether the presence of the light with the tone affected his auditory acuity.

In Table I, the special conditions for each of the six experiments are summarized. The number of sensory conditioning trials, or trials of tone alone for the control group, was 10 except for Exp. II and III, where it was 2 and 20 respectively. The light stimulus was an increase in the general illumination of the room for all experiments except IV where it was a decrease in intensity from 3.40 millilamberts to 2.66 millilamberts. If a threshold to the tone with light present is designated A and a threshold to the tone without light is designated B, the sequence of thresholds for half the *Ss* in the experimental and control groups was ABBAABBA and for the other half was BAABBAAB. These sequences were changed in Exp. VI to AAAABBBB and BBBBAAAA. The auditory threshold was obtained in each case by use of a modified form of the method of constant stimuli and the method of limits (4). However, for Exp. I, II, and III 5 db steps were used, and for Exp. IV, V, and VI 2 db steps were used.

RESULTS

The basic data for analysis are the differences in auditory acuity for the light and no-light conditions of obtaining the thresholds. The inference of sensory conditioning depends upon the difference between the above differences for the experimental and control groups. Therefore, a two-factor analysis of variance was performed on the data of each experiment in order to assess the effect of treatment (sensory conditioning trials versus trials of tone alone), of sequence of the light and no-light threshold conditions, and of the interaction of these two variables. Table II presents

these results, except those for interaction. The interaction term has no meaning with respect to the experimental design and none of the values of *F* approach significance. Examination of Table II shows that auditory acuity is greater for the light condition than for the no-light condition both for the experimental and control groups of each of the six experiments. The magnitude of this difference is greater for the experimental groups than for the control groups in every case. However, in no case is the *F* for treatment significant at the .05 level of confidence. For Exp. III, the *F* for treatment is too small to be worthy of further consideration. For the other experiments, the significance of *F* falls between the .10 and .20 levels of confidence. In most cases it is closer to that for the .10 level than the .20 level.

Scrutiny of Table II shows that only in the case of Exp. II and VI is the *F* for sequence significant at better than the .20 level of confidence. Also, the effect of sequence is reversed for Exp. III and IV from that for the other four experiments. There is little evidence, then, for any differential effect of sequence, particularly the two sequences BAABBAAB and ABBAABBA. There may be a differential effect for the two sequences BBBBAAAA and AAAABBBB, but no conclusions can be drawn in view of the confidence level being larger than the .10 level.

Further consideration was given to the effect of the treatment variable on auditory acuity because in the initial experiment with this technique the results obtained were at better than the .05 confidence level and because in all the experiments presently reported, the results favor the experimental group, even though in no single case is the criterion of the .05 level of confidence satisfied. In the original study by Brogden (**2**) only two thresholds were taken, one each for the light and no-light conditions. Since it is possible that the sensory conditioning effect is dissipated in time, reanalysis of the data for Exp. I through V was carried out for the first two thresholds only (one for the light and one for the no-light condition) and also for trend in terms of successive differences in auditory acuity for the two conditions of threshold measurement. The results for the first two thresholds do not differ from

TABLE II

DIFFERENCES IN AUDITORY ACUITY (IN DB) BETWEEN THE LIGHT AND NO-LIGHT THRESHOLD CONDITIONS AND SUMMARY OF RESULTS BY ANALYSIS OF VARIANCE

Exp.	Prethreshold Treatment				Sequence of Thresholds with Light (A) and without Light (B)			
	T + L	T	Diff.	*F**	BAABBAAB	ABBAABBA	Diff.	*F**
I	1.53	0.35	1.18	2.41	1.12	0.76	0.36	0.35
II	1.40	0.65	0.75	1.87	1.35	0.70	0.65	1.66
III	1.10	0.90	0.20	0.09	0.90	1.10	−0.20	0.24
IV	1.18	0.87	0.31	1.78	0.87	1.68	−0.81	0.27
V	1.13	0.44	0.69	2.48	0.88	0.69	0.19	0.88
VI	1.15	0.39	0.76	2.04	1.21**	0.33***	0.88	2.71

* For Exp. I–V an *F* of 4.13, 2.86, and 1.37 is required for significance at the .05, .10, and .20 level, respectively. For Exp. VI the corresponding values are 4.00, 2.79, and 1.35.
** Sequence in this case was BBBBAAAA.
*** Sequence in this case was AAAABBBB.

those obtained for all thresholds. In no case was there evidence for any trend in the effect as a function of time.

If one disregards variation in sequence, number of pretreatment trials, increase or decrease in brightness of the light stimulus, and magnitude of the db steps in obtaining the auditory thresholds, the data for all six experiments may be combined and a single analysis of variance completed. The grand mean for the experimental group in favor of the light threshold condition is 1.22 db and for the control group is .56 db. The difference between these two means in favor of the experimental group is .66 db. The F for treatment is 10.47 and is significant at better than the .01 level of confidence. The F values for sequence and for the interaction of prethreshold treatment and sequence are 2.60 and .77, respectively. The value of F at the .05 confidence level is 3.84.

Analysis of variance was also completed in a number of combinations of the data from the several experiments. Of these analyses, the one for the combined data from Exp. I and V is most pertinent, since the only difference in experimental conditions is the size of the db step used in obtaining the thresholds, a 5-db step in Exp. I and a 2-db step in Exp. V. The mean difference in acuity between the light and no-light conditions, in favor of the light condition, is 1.33 db for the combined experimental group and .39 db for the combined control group. The difference between these means, in favor of the experimental group, is .94 db. The value of the F for treatment is 6.46, for sequence is .56, and for interaction is 1.27. The required value of F at the .01 level of confidence is 7.07, and at the .05 level is 4.00. The results of analysis of the other combinations of data are comparable to those for the combination of Exp. I and V.

No systematic analysis was made of *Ss'* responses to the questions given at the close of the experiment. Only a few *Ss* reported that they were not aware of the light stimulus. Statements were made that the light increased auditory acuity, that it decreased auditory acuity, that it had no effect, and that *S* did not know whether there was any effect. There appears to be no relationship between these statements and the actual measurements of auditory acuity.

Discussion

The results of these experiments provide further evidence in support of the validity of sensory conditioning as measured through the facilitation of auditory acuity. Although the results for no one of the six experiments alone satisfied the usual criterion of statistical significance, in each case the difference in auditory acuity between the light and no-light conditions, always in favor of the light condition, was greater for the experimental group than for the control group. Moreover, if the variations in conditions from experiment to experiment are disregarded, and the data for all six are combined, statistically significant results are obtained. Statistically significant results are also found by analysis of variance made on other combinations of the data from the several experiments.

No clear-cut evidence was obtained on any of the questions that the several experiments were designed to answer. Variations in the number of sensory conditioning trials, in the light stimulus being an increase or a decrease in brightness, in the size of the db step used to obtain the auditory thresholds, or in the sequence in

which thresholds were given under the light and no-light conditions, were not demonstrated to have any differential effect. The phenomenon probably occurs under all of these conditions, except for the one in which 20 sensory conditioning trials were given (Exp. III). The omission from the present six experiments of the trials of tone and the test trials of light alone that were used in the initial study (**2**) does not appear to have any appreciable effect on the occurrence of the phenomenon.

The present technique for measuring sensory conditioning has the same deficiency as that of the reaction time procedure previously used (**1**). The magnitude of the effect and its reliability are only sufficient to demonstrate the phenomenon, and are insufficient for dimensional analysis of the variables involved that may be manipulated experimentally. Because of this, little advancement has been made in further understanding of the nature of this phenomenon. The difficulty may not be so much with the procedures per se as it is with their application to human beings as *Ss*. There is certainly ample opportunity for the prior learning of human *Ss* to have a marked effect on the occurrence and magnitude of sensory conditioning. Such factors, unfortunately, cannot be controlled or manipulated experimentally.

Finally, it should be noted that the occurrence of sensory conditioning does have a bearing upon theories of learning. However, there is no difference in this respect between sensory conditioning demonstrated by the auditory acuity technique and that demonstrated by the reaction time procedure. Therefore, nothing from the present experiments adds to the discussion of this problem that has not already been presented (**2, 3**).

Summary

The results of a series of six experiments on sensory conditioning measured by the facilitation of auditory acuity are presented. The *Ss* of experimental groups were given trials of a tone and light in combination and *Ss* of control groups were given the same number of trials of the tone alone. Subsequently absolute thresholds were obtained under two conditions; one in which the light accompanied every presentation of the tone and another in which the light was not present. For the experimental and control groups, auditory acuity was greatest when the light accompanied the tone, but this difference was in all experiments greater for *Ss* of the experimental groups than for the control groups. Statistically reliable results were not obtained for any single experiment, but combinations of the over-all data did provide statistically reliable results.

Since the difference in favor of the experimental groups is a function of the sensory conditioning training, further positive evidence of sensory conditioning measured in terms of facilitation of auditory acuity has been obtained. No evidence was found that variation of the several experimental conditions produced a differential effect on auditory acuity. These conditions were number of sensory conditioning trials, increase or decrease in brightness of the light stimulus, size of the db step used in obtaining the auditory thresholds, and sequence of the light and no-light threshold conditions. The phenomenon probably occurs under all of these varied conditions, except for one in which 20 sensory conditioning trials are given (Exp. III).

(Manuscript received January 2, 1951)

References

1. Brogden, W. J. Sensory pre-conditioning of human subjects. *J. exp. Psychol.*, 1947, **37**, 527–539.
2. Brogden, W. J. Sensory conditioning measured by the facilitation of auditory acuity. *J. exp. Psychol.*, 1950, **40**, 512–519.
3. Chernikoff, R., and Brogden, W. J. The effect of instructions upon sensory preconditioning of human subjects. *J. exp. Psychol.*, 1949, **39**, 200–207.
4. Culler, E., Finch, G., Girden, E., and Brogden, W. Measurements of acuity by the conditioned-response technique. *J. gen. Psychol.*, 1935, **12**, 223–227.

A COMPARISON OF AVOIDANCE AND NONAVOIDANCE EYELID CONDITIONING[1]

BY FRANK A. LOGAN[2]

Institute of Human Relations
Yale University

Theorists opposed to the reinforcement interpretation of classical conditioning, especially those contiguity theorists adhering to the cognition viewpoint (**1**, **3**, etc.), have pointed out that the avoidance type of conditioning procedure, in which the occurrence of an anticipatory CR precludes the occurrence of the UCS should, according to a reinforcement theory, be less effective in establishing conditioning than the classical nonavoidance procedure in which *S* receives the USC regardless of the occurrence or the nonoccurrence of the CR. This prediction is correctly inferred from a reinforcement theory since, in the avoidance type of conditioning, those trials on which a CR occurs do not contain the UCS. The response is therefore not reinforced on these trials, while, in contrast, reinforcement occurs on every trial in nonavoidance conditioning. This circumstance should, according to a reinforcement theory, favor the latter procedure in the establishment of CR's because, obviously, it involves a greater number of reinforcements within a given number of trials.

These critics have cited an experiment by Brogden, Lipman, and Culler (**2**) as evidence against this reinforcement interpretation. In this experiment the running response in guinea pigs was conditioned to a 1,000-cycle tone presented 2 sec. before a shock, under both avoidance and nonavoidance conditions. In terms of per cent frequency of conditioned running responses, the avoidance group conditioned rapidly. The nonavoidance group began equally well, but leveled off considerably below the maximum of the avoidance group and then actually decreased. The *E*s concluded that the avoidance procedure was superior in establishing conditioning.

These critics of a reinforcement interpretation of classical conditioning have failed, however, to take into consideration certain observations originally reported by Brogden, Lipman, and Culler (**2**), but analyzed more completely by Sheffield (**5**) after a repetition of the experiment. In the nonavoidance conditioning, once a conditioned running response occurred, the arrival of the shock tended to elicit not a more vigorous running response, but a non-running response (crouching, sprawling, etc.). Conditioning of the running response was therefore retarded by the counter-conditioning of an incompatible (non-running) response. By a further analysis of his data, Sheffield found that if the response to shock on the previous trial had been continued running, the frequency of conditioned running on the ensuing trial increased from about 40 to about 50 per cent. But the frequency of CR's on the next trial dropped from 40 to 20 per cent when

[1] Submitted in partial fulfillment of the requirements for the M.A. degree in the Department of Psychology in the Graduate College of the State University of Iowa.

[2] The writer is indebted to Prof. Kenneth W. Spence for his invaluable cooperation in the analysis of the problem and preparation of the manuscript.

the response to shock on the previous trial was non-running.

This type of experiment therefore involves two competing CR's: first running, and later non-running. As the frequency of the former increases, the UCS more often elicits a non-running response; this latter form of behavior then tends to occur to the CS. Since the two responses are obviously incompatible, the occurrence of a conditioned non-running response must reduce the incidence of conditioned running. The low frequency of conditioned running responses in the nonavoidance group is therefore entirely consistent with a reinforcement theory.

It is, however, necessary to account for the continued conditioning of the avoidance group, since the reinforcement furnished by the UCS was not present on successful avoidance trials. A theoretical account of the possible nature of the reinforcement in avoidance conditioning has been provided by Mowrer (**4**) in terms of the drive (fear) properties of the CS. The CS comes to evoke the emotional response elicited by the unconditioned (nociceptive) stimulus. The onset of the CS thus leads to an increase in the drive level of *S*; the termination of the CS provides a reduction in this anxiety. Secondary reinforcement may therefore be present even on successful avoidance trials when the primary reinforcement dependent upon the UCS is not given. This secondary reinforcement would, however, be expected to extinguish during successful avoidance trials. Data reported by Sheffield (**5**) are consistent with this expectation. Over each series of successful avoidance trials, the amplitude of the conditioned running response became smaller, and the latency longer. These extinction effects continued until a reinforcement with shock reinstated the avoidance behavior and the secondary reinforcing properties of the CS. The continued conditioning that has been obtained using the avoidance procedure is therefore explicable in terms of reinforcement principles.

The purpose of the present experiment was to compare the effectiveness of the avoidance and nonavoidance conditioning procedures in the establishment of the conditioned eyelid response in human *S*s. In this type of conditioning experiment, the UCS continues to elicit the same UCR (eyelid closure) even after anticipatory CR's appear. Such a situation does not involve, therefore, the counter-conditioning of a competing response, as was seen to occur in the conditioning studies involving locomotion. According to the reinforcement theory, the rate of conditioning with the nonavoidance procedure should be equal, if not superior, to that obtained with the avoidance technique.

Method

Subjects.—Thirty undergraduate psychology students served as *S*s. Half of the *S*s, selected at random, were trained under the avoidance procedure, and half under the classical nonavoidance technique.

Apparatus.—The apparatus functioned in such a manner as to present a light for 470 msec., during the last 20 msec. of which a shock was delivered near *S*s right eye (a second electrode was placed on the back of the right hand). The eyeblink was recorded by means of a mechanical lever fixed to the headgear and fastened to the eyelid. This attachment was adjusted so that an eyelid closure of $\frac{1}{8}$ in. from the normally fixated position caused a thyratron to fire and an eyeblink to be recorded. A DC clock was started at the onset of the light and was stopped by the occurrence of the blink. Latency of response was read directly to the nearest .01 sec. Because responses occurring prior to 150 msec. were not considered CR's, the apparatus was arranged so that eyeblinks before this time did not stop the clock or avoid the shock.

The *S*s were comfortably seated in a partially soundproofed room, under constant illumi-

nation of .15 ft.-candles. The stimulus disk was always illuminated to a level of .2 ft.-candles, which was raised to 30 ft.-candles on the occurrence of the CS. An electric fan provided air circulation, and a sound-screen insured against extra auditory cues in the situation. The *E* was in another room.

Procedure.—After the shock had been adjusted to *S*'s tolerance level, directions designed to minimize concern about the purpose of the experiment were read.

At random intervals of 2, 3, or 4 sec. before the CS was presented, a weak buzzer was given to serve as a ready signal. The *S* was instructed to wink once voluntarily to this signal. The light was then presented, followed at 450 msec. by shock, unless automatically avoided by a CR in the avoidance group. This was the only systematic difference between the groups. One hundred such acquisition trials were given with an intertrial interval average of 15 sec., in a fixed irregular order of 10, 15, or 20 sec.

Extinction trials, during which no shock was administered to either group, were begun immediately on Trial 101. They were continued until *S* failed to respond on five successive trials.

Results and Discussion

The results for the two groups are presented graphically in Fig. 1, which shows the mean per cent CR's in successive blocks of ten trials. The curve for the nonavoidance group will be seen to compare favorably with typical classical conditioning data obtained in other situations, suggesting that the comparison of the avoidance and nonavoidance results is justified as representative of the purpose of the experiment. In contrast, the avoidance group demonstrated little, if any, conditioning.

When the difference between the two groups was tested over the last ten acquisition trials by means of the Mann-Whitney *U*-test, it was found that the probability that the nonavoidance procedure was not superior to the avoidance technique is .01. The results of the present study are therefore directly in line with the prediction based upon a reinforcement interpretation of classical conditioning.

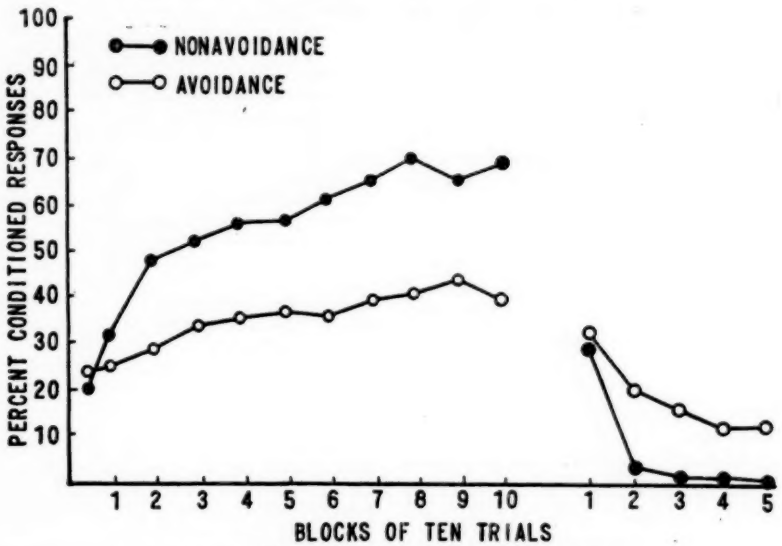

Fig. 1. Acquisition and extinction curves for nonavoidance and avoidance eyelid conditioning (means)

An examination of the extinction curve for the avoidance group shows it to be relatively prolonged in comparison with typical human eyelid extinction curves. Sheffield (6) has inferred that one variable affecting resistance to extinction is the extent to which traces of stimuli from the preceding trial that are components of the conditioned stimulus complex, differ between acquisition and extinction. In nonavoidance conditioning, the CS during acquisition always contains the trace of the UCS from the previous trial. Avoidance conditioning, on the other hand, is essentially a partial reinforcement situation in which the CS sometimes contains the trace of shock from the preceding trial and sometimes does not. The CS for the avoidance group during extinction is thus more similar to the CS during acquisition than is true for the nonavoidance group. The greater resistance to extinction of the avoidance group in the present experiment, therefore, is consistent with an assumption that the traces of stimuli from preceding trials may be components of the conditioned stimulus complex.

Summary

1. Thirty human *Ss* were presented with a light-shock conditioning sequence, half under avoidance and half under nonavoidance conditions.

2. Avoidance conditioning was significantly inferior to nonavoidance conditioning.

3. Avoidance *Ss* show relatively prolonged extinction curves. This is consistent with experimental data on resistance to extinction following massed partial reinforcement training.

(Manuscript received January 4, 1951)

References

1. Birch, H. G., and Bitterman, M. E. Reinforcement and learning: the process of sensory integration. *Psychol. Rev.*, 1949, **56**, 292–308.
2. Brogden, W. J., Lipman, E. A., and Culler, A. The role of incentive in conditioning and extinction. *Amer. J. Psychol.*, 1938, **51**, 109–117.
3. Maier, N. R. F., and Schneirla, T. C. Mechanisms in conditioning. *Psychol. Rev.*, 1942, **49**, 117–134.
4. Mowrer, O. H. Fear as an intervening variable in avoidance conditioning. *J. comp. Psychol.*, 1946, **39**, 29–50.
5. Sheffield, F. D. Avoidance training and the contiguity principle. *J. comp. physiol. Psychol.*, 1948, **41**, 165–177.
6. Sheffield, Virginia F. Extinction as a function of partial reinforcement and distribution of practice. *J. exp. Psychol.*, 1949, **39**, 511–526.

THREE DEMONSTRATIONS INVOLVING THE VISUAL PERCEPTION OF MOVEMENT [1]

BY F. P. KILPATRICK AND W. H. ITTELSON

Princeton University

Many familiar demonstrations of phenomena involved in static visual perception are available to the classroom instructor and the laboratory investigator. In contrast, few demonstrations concerning the perception of movement are in common use: unfortunately the study of motion perception forces one to replace paper and pencil with elaborate and often expensive mechanisms. Understanding has not been entirely thwarted by complexity and cost, however, and a growing body of literature is available dealing with diverse aspects of this question. This paper will describe three demonstrations which, taken together, encompass a fairly wide area of the visual perception of movement.

It seems useful at the outset to distinguish between two different principal directions of perceived movement. One, directly toward or away from the point of observation, can be labeled *radial movement*, while the other, at a constant radial distance, can be termed *tangential movement*. These principal directions of motion are clearly analogous to the familiar static *depth* and *direction*, and, just as in the static case, one would expect different types of cues to be utilized by the organism in the two different cases.

[1] The demonstrations described in this paper were designed by Adelbert Ames, Jr., and constructed under his direction at the Institute for Associated Research, Hanover, N. H. Special acknowledgment is due the Rockefeller Foundation for the financial aid which made this work possible.

Demonstration I: Radial Motion

This demonstration is concerned with the role of continuous change of size as an indication of continuous movement in a radial direction. That such an effect does take place was apparently first appreciated by Wheatstone (**13**) and has since been studied in a variety of contexts (**1, 3, 7, 8, 11**). The apparatus discussed below contains within it means for demonstrating virtually all that is known regarding this particular phenomenon.

A light box (*A* in Fig. 1), on the front of which is a square diaphragm opening (*B*), is driven back and forth on a track (*C*) through a distance of 6 ft. by an electric motor. The opening is observed, in an otherwise dark room, from a distance of 6 ft. from the shield (*F*) at the near end of the track. The square diaphragm opening is formed by two metal plates (*D*) moving in slots on the front of the light box. Each of these metal plates engages one of a second pair of tracks (*E*) whose inclination and separation can be varied. As the box moves back and forth, variations in the size of the diaphragm opening are controlled by the inclination of this second pair of tracks. If they are set parallel, the size of the opening remains constant. If the tracks are set so that they converge towards *O*, as in the figure, the size of the diaphragm decreases as it moves toward *O*; if they are set so they diverge, the size of the diaphragm increases as it approaches *O*.

When *O* views this apparatus under various conditions of monocular and binocular observation and with various separations and inclinations of the tracks, certain consistent and predictable perceptions are experienced.

1. When the tracks are set parallel, *O* looking with both eyes sees a square of constant size moving back and forth at a constant speed, approaching

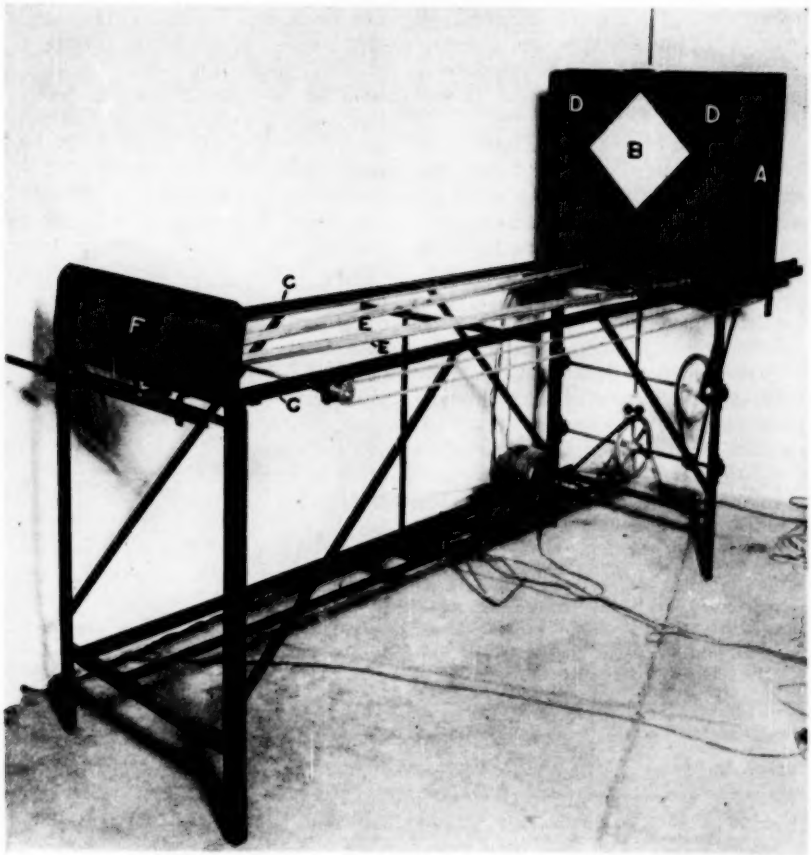

FIG. 1. The radial motion apparatus. The light box *A* is driven back and forth on the tracks *C* and *C*. As it moves, the size of the diaphragm opening *B* changes in a manner determined by the setting of the tracks *E* and *E*.

to a distance from him of approximately 6 ft. and receding to a distance of approximately 12 ft. (Cond. I, Fig. 2). His perception in this case corresponds to the actual objective situation.

2. If *O* looks with one eye, he sees substantially the same thing (Cond. I, Fig. 2).

3. If, under these conditions, the tracks are then converged so that the opening subtends a constant visual angle as it moves back and forth, *O* sees the square standing motionless at the apparent distance at which it was localized at the moment that the tracks were converged (Cond. II, Fig. 2).

4. If the tracks are converged still more to just the right amount, *O* will again see a square of constant size moving back and forth at a constant

speed through a distance from him of 6 to 12 ft., but the apparent direction of movement will now be opposite to that of the actual movement (Cond. III, Fig. 2).

5. If both eyes are used under the conditions described in 4 above, the effect continues to be experienced by most *O*s to a greater or less extent, persisting even when stationary objects are placed in the field of view to provide more adequate binocular localization. Great individual variations are encountered here.

A further most interesting phenomenon can be illustrated with this apparatus. The tracks are first set parallel with a medium separation. Conditions 1, 2, 3, and 4 above are then successively presented to *O* who, under Cond. 1, 2, and 4, sees a square of medium size moving at a constant speed from a point 6 ft. away to a point 12 ft. away and back again. It should be noted that the apparatus is so designed that the sequence 2–3–4 can be carried out smoothly, without any sudden jumps in the size of the moving diaphragm. The tracks are then set to Cond. 1′, that is, parallel but with a greater separation than under the original Cond. 1. Under these conditions, using both eyes, *O*'s perception of the distance, direction, and speed of movement remains unchanged; he simply sees a larger square. After *O* has looked for a few moments, one of his eyes is blocked off (Cond. 2′), but, as before, he experiences no significant change in his perceptions. Without giving *O* any indication of exactly what is being done, the tracks are then shifted back to the original Cond. 4, the apparatus being so designed that this can be accomplished smoothly without introducing any sudden jumps in the size of the stimulus. This condition provides exactly the same external situation and retinal stimulus pattern which had previously been perceived as a square of fixed size moving at a

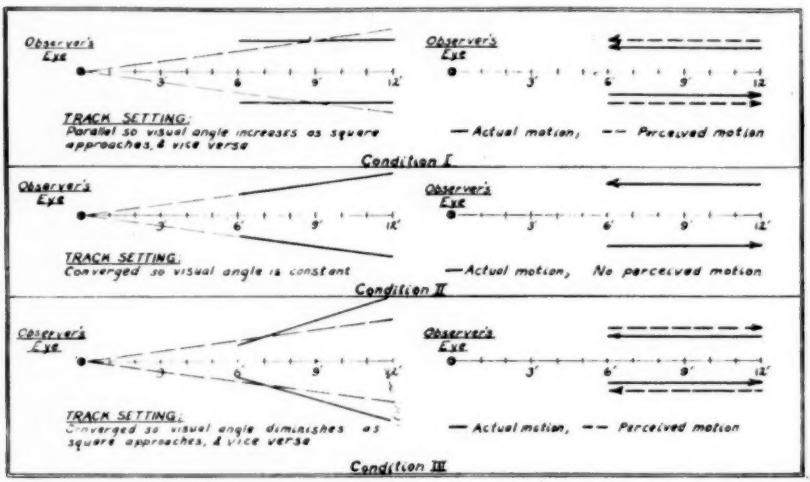

FIG. 2. Perceived motion of the lighted diaphragm (*B* in Fig. 1) under three conditions of observation. The actual motion is the same under all three conditions, but the perceived motion varies with the track setting.

constant speed from 6 to 12 ft. But now *O* perceives it as a *larger* square, moving through a *greater* distance, *farther* away from him, and at an *increased* and *variable* rate of speed. This effect continues even when the original Cond. 2 is presented again, which may be accomplished by presenting Cond. 4, 3, and 2 in that order.

Many variations of this basic effect are possible, involving, for example, a shift toward rather than away from *O*. All of these variations, however, seem to involve the same process. When *O* first looked at the smaller square, he perceived a square of constant size moving back and forth at constant speed from 6 to 12 ft., which in fact corresponded to the actual external situation. In terms of retinal stimulation, this means that a square retinal pattern (disregarding distortion) continuously changing in size was related to the perception of a square of constant size continuously moving in space. When the shift was made to the larger square, the same effect was obtained, reinforced initially by the use of binocular indications. The interesting point, of course, occurs when, in monocular observation, the actual size of the square is reduced to the original, smaller size. It should be noted that the procedure is such that *O* is unaware of this change and assumes that he is still looking at the larger square. As a result of this assumption[2] the identical pattern of retinal stimulation, which just previously had been related to the perception of a small square moving at constant speed through a certain distance, is now related to the perception of a larger square, farther off, moving through a greater distance, and at a variable speed. To state this more generally, there are an unlimited number of objective, external events which will produce the same sequence of retinal patterns. Which one of these external events will in fact be perceived depends on the particular assumptions (in this case primarily that of size) which the individual brings to the occasion.

[2] The role of assumptions in perception has been discussed at length elsewhere by the authors and others (1, 2, 4, 5, 6, 8, 9, 10, 12).

Demonstration II: Circular Motion

The second apparatus to be described involves the perception of circular motion. It is photographed in Fig. 3 and schematically represented in Fig. 4.

As shown in Fig. 4, this apparatus contains a mount (*A*) which is electrically driven so that it oscillates through an arc (*BCD*) of about 40° at a distance of 8 ft. 9 in. from *O*'s eye (*E*). The rate of angular movement about this point (*E*) is mechanically controlled to be the same as that which would result from an object describing a hypothetical circle (*BFDG*) with a 3-ft. radius at a constant angular velocity about a center (*C*) 8 ft. 9 in. from *E*. This means that the angular velocity about the observation point (*E*) is variable, being zero at the two end-points (*B* and *D*) and reaching a maximum halfway between them. This maximum, furthermore, is greater for movement in one direction (in our case, left to right, or *BCD*) than in the other direction (right to left, or *DCB*).

When a small star point of light is placed on the oscillating mount (*A*), an *O* using one eye in an otherwise dark room sees it as moving in a shallow ovate arc approximately as indicated by the dotted lines in Fig. 4. Its apparent speed of movement is variable, being considerably greater in one direction (left to right) than in the other direction. We stress here that the star point does not appear to swing from side to side at a constant distance from *O* as it is actually doing, but rather, it is seen appreciably nearer *O* during the period of high angular velocity and appreciably far-

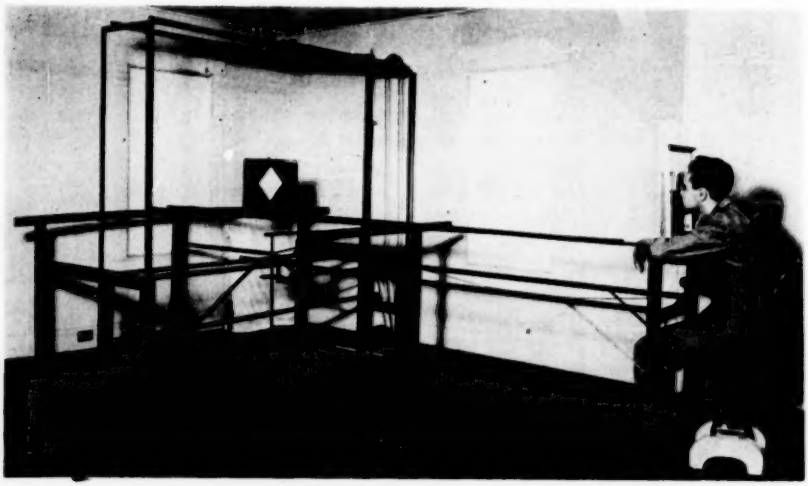

FIG. 3. Circular motion apparatus showing the light box with variable size square diaphragm opening in place on the oscillating mount

ther away during the period of low angular velocity, resulting in a roughly elliptical path of perceived movement.[3]

We now replace the star point with a light box having a variable size square diaphragm opening similar to that used in the radial motion demonstration described above. If the size of this opening is kept constant as the square swings from side to side, *O* using one eye sees a constant size square swinging from side to side at variable speeds at a constant distance from him, i.e., true tangential movement at variable speed, which in this case corresponds to the actual movement. It is possible, however, by means of a mechanical linkage, to vary the size of the diaphragm opening in such a way that the angle it subtends to *O*'s eye exactly corresponds at all times to the angle that would be subtended by a square surface normal to *O*'s line of sight moving in a counterclockwise direction about the hypothetical circle pictured in Fig. 4. When *O* now looks at this square diaphragm, which is changing its size at a variable rate and swinging in a shallow arc at variable speed, he sees a square of constant size moving in a circle at a constant rate of speed.

It is evident from the above described effects that objective tangential movement can be related to a

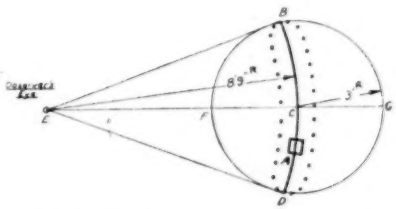

FIG. 4. Schematic representation of the circular motion apparatus

[3] It is worth noting also that a star point which remains at the same height as *O*'s eye and is actually moving in the circle *BFDG* at a constant speed is perceived in exactly the same way; that is, as moving in the roughly elliptical path indicated by the dotted lines in Fig. 4.

number of perceived movements, depending on the other indications available. In the case of the star point, relative angular velocities at different times served as an indication of relative apparent distances at these times. This effect is clearly related to the familiar depth cue of parallax, with the important modification that the relative angular velocities occur at different times rather than simultaneously. It would seem evident that a perceptual integration along a temporal dimension is involved here. However, if angular velocity serves as an indication of distance, even more striking is the effect of apparent distance in determining apparent velocity. Apparent circular movement at constant speed resulted from the addition of appropriate indications of relative distance. Or, to state this more precisely, circular movement at constant speed was the correlate in experience of appropriate indications of tangential movement at variable speed plus radial movement at variable speed.

Demonstration III: A Case of Conflict

A given movement across the retina, e.g., movement in a constant direction at a constant speed, can be produced by an infinity of external, objective movements; and, of course, this relationship becomes even more complicated when eye and head movements and bodily orientation are taken into account. The related perception, however, can obviously be of only one of this infinity of objective conditions. Ordinarily other aspects are available, such as size, brightness, etc., to determine the particular perception, but these other indications are themselves not unequivocal and may even be in conflict. The demonstration described below shows how real, objective tangential movement[4] may be perceived as a variety of apparent movements when some of the other indications are systematically altered.

A thin metal trapezoidal shape with openings corresponding to window panes (inset, Fig. 5) is placed, relative to *O*'s eye, in the position *A'B'* (Fig. 5). When viewed monocularly under these conditions, the physically near edge (*A'*) becomes the apparently far edge (*A*), and the physically far edge (*B'*) becomes the apparently near one (*B*). The resulting perception is of an approximately rectangular "window" in the position *AB*. The photographs in Fig. 6 will give an idea of the way in which the trapezoid is perceived.

A small electric motor drives a fine thread in such a way that light objects suspended from it, e.g., a small card cut out of paper, can be driven across the field of view at a constant speed along the straight path *CD* (Fig. 5), passing through one of the near openings of the trapezoid, which to *O* is one of the apparently far openings.

However, it is not perceived as moving in such a straight path; rather, it is seen as following the approximately S-shaped course indicated by the dotted line *EF* (Fig. 5). The nature of this illusory movement is dependent on the fact that *O* sees the trapezoid as a rectangular shape in a position different from its true position. As the card moves across the field of view, it is initially to the right of the "window" and appears against a homogenous background (*I* in Fig. 5 and 6). Under these conditions it is seen as constant in size moving from right to left at a constant speed in a direction parallel to *O*'s frontal plane. When it moves to a position such that part of it is behind the near edge of the trapezoid, it appears to be passing behind the far edge of the apparent rectangle (*II* in the figures). As the

[4] The movement employed in the demonstration is not, strictly speaking, tangential. It is straight-line movement at right angles to a fixed line of sight, with consequent variation in radial distance. However, since the variation in radial distance is very small in the demonstration, it seems fair to speak of the motion as tangential.

card moves completely through the near opening of the trapezoid, it comes between *O* and successively farther parts of the trapezoid. To *O*, however, it appears to be passing in front of successively nearer parts of the apparent rectangle (*III* and *IV* in Fig. 5 and 6). The card, therefore, appears to be moving toward *O* parallel to the apparent plane of the rectangle and at the same time decreasing in apparent size. It finally appears to pass completely in front of the rectangle and continue to travel in a straight line at a constant speed and size (*V* in the figures). The distance from *O* at which the card is moving before and after it passes the trapezoid cannot be judged accurately.

In summary of this particular effect, movement of a constant size object, travelling at a constant speed in a constant direction at a virtually constant distance from *O*, is perceived as an object of varying size travelling in varying directions and at varying speeds and distances. This perceived movement through an approximately S-shaped path is, as indicated earlier, only one of an infinite set of movements which might be perceptually related to the given objective movement. Broadly speaking, this particular effect is achieved by placing the constant size, speed, and direction of the moving object in conflict with the over-lay indications from the falsely localized trapezoid. Over-lay proves more effective for all *O*s, and the above described movement is perceived.

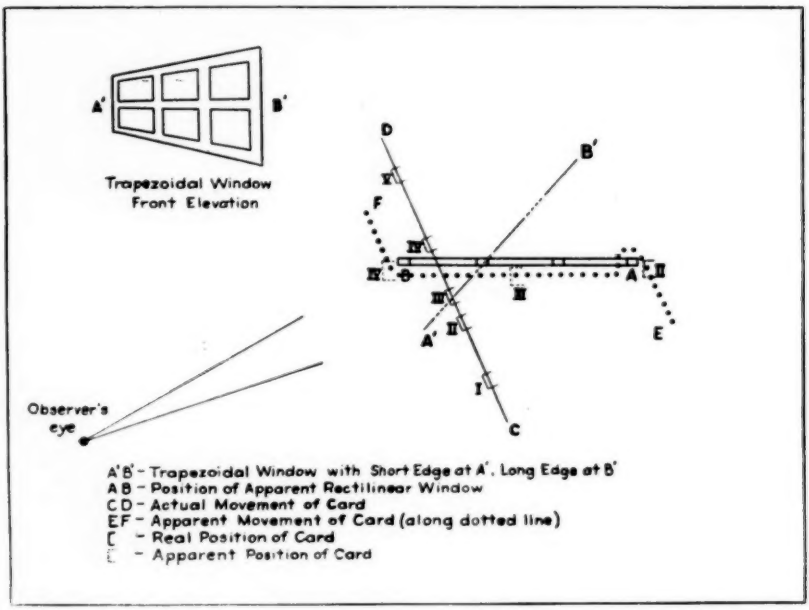

FIG. 5. Diagram showing the real and apparent positions of the trapezoid and the real and apparent paths of the moving card in the tangential motion demonstration. Direction of movement is from positions *I* to *V* along the line *CD*.

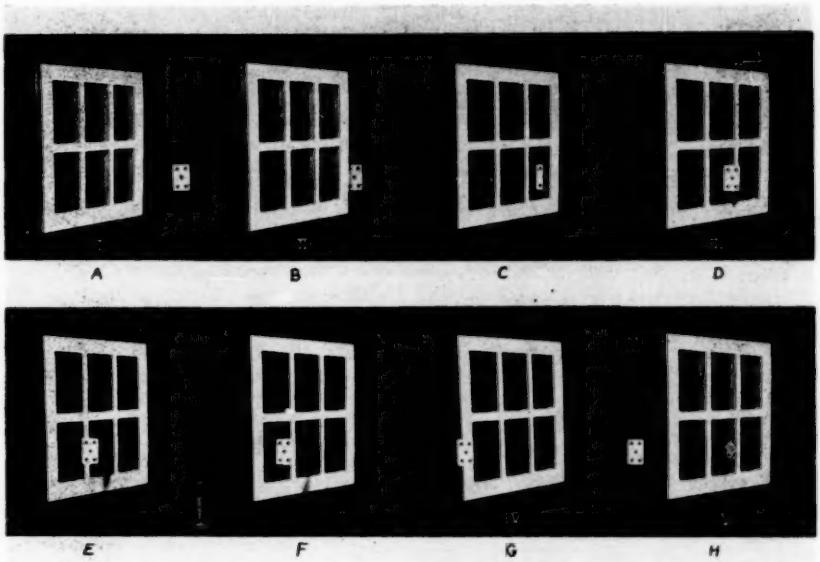

FIG. 6. Eight successive positions of the card in the tangential motion demonstration. The frame appears to be tipped back with the right side farthest from the camera; actually the reverse is true. The white roman numerals indicate the five positions corresponding to those shown in Fig. 5.

Not all *O*s, it should be added, see the apparent size change. Many continue to see the moving card as constant in size even when specifically questioned, and in spite of the fact that they perceive the movement in depth quite dramatically. This is merely evidence that in any perceptual situation involving conflicts, differential individual behavior is to be expected, with greater differences occurring the more nearly the two, or more, possible ways of perceiving are equated in terms of probability of occurrence. This can be most startlingly illustrated with the apparatus described here by placing not only the object, but also the trapezoid in motion. The resulting effects are too complex to be reported briefly and can be found in detail elsewhere (**2, 10**).

SUMMARY

Three demonstrations illustrating various phenomena involved in the visual perception of movement were described in some detail. The first dealt with the role of continuous size change as an indication of continuous movement in the radial direction. The next demonstration considered indications of radial movement in conjunction with indications of tangential movement, specifically as integrated in a perception of circular motion. The third demonstration treated some aspects of the effect of perceptual conflicts in a situation involving objective tangential motion. Implications for perceptual theory were briefly discussed.

(Manuscript received
January 8, 1951)

References

1. Ames, A., Jr. *Some demonstrations concerned with the origin and nature of our sensations (what we experience). A laboratory manual.* (Mimeo.) Hanover, N.H.: Hanover Institute, 1946.
2. Ames, A., Jr. Visual perception and the rotating trapezoidal window. *Psychol. Monogr.*, 1951, **65**, Whole No. 324.
3. Calavrezo, C. Über den Einfluss von Grössenänderungen auf die Scheinbare Tiefe. *Psychol. Forsch.*, 1934, **19**, 311–365.
4. Cantril, H. *The "why" of man's experience.* New York: Macmillan, 1950.
5. Cantril, H., Ames, A., Jr., Hastorf, A. H., and Ittelson, W. H. Psychology and scientific research. *Science*, 1949, **110**, 461–464, 491–497, 517–522.
6. Hastorf, A. H. The influence of suggestion on the relationship between stimulus size and perceived distance. *J. Psychol.*, 1950, **29**, 195–217.
7. Hillebrand, F. Das Verhältnis von Accommodation und Convergenz zur Tiefenlokalisation. *Z. Psychol.*, 1894, **7**, 97–151.
8. Ittelson, W. H. Size as a cue to distance. *Amer. J. Psychol.*, 1951, **64**, 54–67, 188–202.
9. Ittelson, W. H., and Ames, A., Jr. Accommodation, convergence, and their relation to apparent distance. *J. Psychol.*, 1950, **30**, 43–62.
10. Kilpatrick, F. P. Some aspects of the role of assumptions in perception. Unpublished Ph.D. thesis, Princeton Univ., 1950.
11. Metzger, W. Tiefenerscheinungen in optischen Bewegungsfeldern. *Psychol. Forsch.*, 1934, **20**, 195–260.
12. Smith, W. M. Past experience and perception: a study of the influence of past experience on apparent size and distance. Unpublished Ph.D. thesis, Princeton Univ., 1950.
13. Wheatstone, C. Contributions to the physiology of vision. Part the second. *Philos. Mag.*, 1852, Ser. 4, **3**, 504–523.

GENERALIZATION OF A MUSCLE ACTION POTENTIAL RESPONSE TO TONAL DURATION

BY JOHN B. FINK AND R. C. DAVIS

Indiana University

Hull has offered an explanation of stimulus generalization by making use of ***habit strength***, an inferred construct. Habit strength is defined, in this connection, in terms of sigma units corresponding to response proportions, where the measure consists of occurrence or nonoccurrence of the response. The proportions are converted to sigma values by means of the normal probability table, or in more recent work by a special table (**11**). An example of this is found in a study by Czehura (**1**). Herein is a suggestion of an underlying, continuous process.

An alternative interpretation of per cent response occurrence is that the response actually occurs or does not occur, an all-or-none notion; i.e., that there is a discontinuity of response and nonresponse with a variation in something else, say the perceptual assimilation or the common elements of the stimuli, to account for the differing per cents making the generalization gradient. This view would seem related to Lashley's discontinuity theory of learning.

The present study has sought to detect nonovert responses and their variations in magnitude, and to compare them with overt response proportions. Specifically: (a) Is there a stimulus generalization gradient when the stimulus is tone, varied in the dimension of duration, and the dependent variable is a muscle action potential accompanied by a key pressing response? (b) Can the number of overt responses be predicted from the mean action potential at each stimulus duration?

Apparatus and Procedure

The techniques for measuring muscle action potentials, as well as the design and testing of equipment for recording action potentials, have been discussed by Davis (**2, 3**) who has also described (**4**) the integrators and some of the accessory apparatus used in this investigation. Records were made by a six-pen Electro-Medical Laboratories recorder into which the output of the integrators was fed through a stage of power amplification.

Two independent amplifying systems were used to measure the muscle action potentials. Since we wished to measure both large and small potentials, we arranged that each amplifier would feed into two integrators, one operating at high gain, one at low. Thus two recorder pens recorded the same phenomenon at different sensitivities. The active electrode of each system was in contact with the surface of the appropriate forearm adjacent to the extensor digitorum muscle. The reference electrode consisted of a large thick pad on the upper arm. A sample of the kind of record taken has been presented by Davis (**5**). Though records were taken from both arms, the results here reported are those from one only, i.e., the arm designated to press the key.

The tones, produced by a Hewlitt-Packard oscillator, were fed into an electronic timer modified from a design published by Roush (**15**) and from there into a loudspeaker in the experimental room. The timer delivered one tone of predetermined duration when activated by *E*.

The *S*s were 25 students who had either one year or less of psychology courses.

The *S* was seated in front of the response table in a shielded, dark, sound-insulated room, and was given preliminary instructions to relax as completely as possible. Then *S* was presented with three series of tones. The series were separated by a 2-min. rest period. In each series, the tones were presented 30 sec. apart, each tone preceded, by 2 sec., by a verbal "Ready!" signal presented through the loudspeaker. The *S*'s response was the pressing of a telegraph key with the middle finger of the preferred hand. His responding hand and the response key were confined in a box-compartment. The wrist was held firmly to the table by means of an elastic band 3 in. wide. The nonpreferred hand was

similarly confined, the compartment containing a dummy key. The key-spring was adjusted so that only a forceful pressing by *S* would depress the key.

Tone Series I.—The *S* was instructed to respond to every tone: "You are going to hear a series of sound signals like this (*Present tone*). Before each sound signal, you will hear me say, 'Ready,' to warn you that the signal is about to occur. When you hear the signal, press the key just as quickly as you can after the signal is over."

Each *S* was given 3 preliminary practice trials followed by a 15-trial presentation series. The series consisted of three randomized presentations each of five kinds of tones, constant in frequency and intensity, differing only in duration. These shall be designated as D_0, D_1, D_2, D_3, and D_4. Their durations, in order, were 2, 2.25, 2.5, 3, and 4 sec. This series was a control procedure designed to ascertain the extent to which size of action potential is a function of duration of tone.

Tone Series II.—The *S* was instructed to respond to a series of tones of duration D_0 (2 sec.). Instructions were: "You are going to hear another series of sound signals. This time they will all be exactly alike. As you hear each signal, press the key just as quickly as you can after the signal is over."

Each *S* was given ten training trials.

Tone Series III.—Each *S* was placed into one of five groups: D_0, D_1, D_2, D_3, or D_4, the nomenclature here corresponding to that for the tones in Series I. Tone Series III was then presented. For groups D_1 to D_4 this consisted of 20 tones, 10 of which were the original training tone, and 10 of which were the tone for which the group was designated. Group D_0 received 20 presentations of the original tone.

TABLE I

Order of Presentation of Stimuli: Series I

D_4	D_1	D_1	D_3	D_2
D_2	D_4	D_2	D_1	D_0
D_3	D_0	D_3	D_0	D_4

All groups received the same instructions: "You are going to hear another series of sound-signals. There may be several kinds of sound-signals in this series. Some of them will be exactly like the ones you have just heard in the last series, like this (*Present* D_0). Others may be different in some way. When you hear a sound-signal exactly like the ones in the last series, press the key just as quickly as you can after the signal is over."

The order of presentation of stimuli in Series I is indicated in Table I. Numerical representations of the stimuli were drawn, in the order presented, from the table of random numbers of Fisher and Yates as reprinted in Lindquist (**13**). The first *S* in each group was presented the order shown in the table. The second *S* in each group began with Column 2 of the table, proceeded through Columns 3, 4, and 5, and ended with Column 1. The third *S* began with Column 3 and ended with Column 2, and so on for all five *S*s. This was a control for position effects.

TABLE II

Order of Presentation of Stimuli: Series III

D_x	D_0	D_x	D_x	D_0
D_0	D_0	D_0	D_0	D_0
D_x	D_x	D_0	D_0	D_x
D_x	D_0	D_x	D_0	D_x

The order of presentation of stimuli in Series III is indicated in Table II. The tone D_0 was presented wherever D_0 appears in the table. Wherever D_x appears in the table, one of the five tones was presented, D_x being constant for a given group, e.g., Group D_2 received tone D_2 wherever D_x appears in the table.

It will be noted that the term, *sound-signal*, rather than the more conventional term, *tone*, was used in the instructions; comments of some preliminary *S*s indicated that the term, *tone*, carried the connotation of frequency or pitch.

The phrase, "after the signal is over" was used in the instructions to counteract the tendency observed in preliminary *S*s to anticipate the signal.

Measurement was effected in the following manner. The highest peak obtaining in the 2-sec. interval following termination of the stimulus was measured in millimeters and, by means of prior calibration, translated into microvolts. The measure $\log R_x - \log R_0$ was used, where R_0 represents action potential response in microvolts to duration D_0, and R_x represents action potential response in microvolts to durations D_0, D_1, D_2, D_3, or D_4. This transformation was assumed to cancel out differences in rest level by virtue of a relation which generally appears to hold; that response level is proportional to rest level (**5**). Microvolt ratios, R_x/R_0, would have served the same purpose, but the log measure was deemed preferable for statistical purposes when a distribution of log microvolt differences was found to approximate the normal curve more closely; the distribution of microvolt ratios manifested a marked skew.

Results and Discussion

The group means of the response measures in log microvolt differences

TABLE III

RESPONSE MEASURES IN LOG MICROVOLT DIFFERENCES FOR DIFFERENT DURATION GROUPS IN SERIES III

Ss*	Durations				
	D_0	D_1	D_2	D_3	D_4
1	.1158	−.3118	.0056	−.2170	−.2540
2	−.0326	−.0291	−.2304	−.4691	−.3625
3	.0068	−.2919	.0080	−.4310	−.4934
4	.0844	−.0256	−.0405	−.7117	−.6608
5	−.2704	−.0393	.0225	−.5862	−.3223
Mean	−.0192	−.1395	−.0469	−.4830	−.6186

* Different *Ss* are represented in each column.

for the different tone durations in Series I, where all *Ss* responded to all durations, were .0000, −.0055, −.0236, −.0116, and −.0186 for durations D_0, D_1, D_2, D_3, and D_4, respectively. The within-cells variance was used as the error term in the *F* fraction, the numerator of which was the variance due to durations. The obtained *F* of 1.23 is far below significance at the .05 level of confidence for 4 and 250 *df*. Interaction effect was found to be non-significant, the appropriate *F* value being .79 for 96 and 250 *df*.

The individual means and group means of the response measures in log microvolt differences for the different duration groups in Series III, the test series, may be seen in Table III. Within-groups variance was used as the error term since the design here did not permit elimination of individual differences from the error variance. The obtained *F* of 4.23 for 4 and 20 *df* is significant between the .05 and .01 levels, the required *F*'s for these levels being 2.87 and 4.43, respectively.

Figure 1, a plot of group means of response measures in Series III (test series) against duration, offers an answer to the first problem in this investigation: Is there a generalization gradient? A straight line fitted to the points by the method of least squares is represented by the equation: $R = -3.49D + 6.98$, where D is the duration of tone in seconds, and R is the mean response measure in log microvolt differences. It can hardly be stated, on our evidence, that the gradient is linear, but the curvature, if any, seems small.

The data might, however, be interpreted as agreeing with Razran's hypothesis (**14**) of a stepwise progression of the gradient, with the first three points on one level, and the last two on a lower level. Our data are not precise enough to determine the form of the gradient.

It will be noted that abscissa units in Fig. 1 are in terms of seconds of duration in contrast to the JND units used by Hovland (**7, 8, 9, 10**) and Humphreys (**12**). Since *stimulus generalization* connotes the operations of measuring response as a function of different stimulus values, it seems more justifiable to plot response meas-

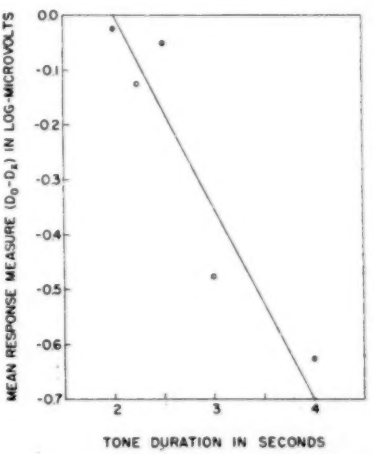

FIG. 1. Mean response measures in log microvolts as a function of tone duration in seconds after ten "training" presentations of the 2-sec. tone. The values of the slope constant and the intercept of the vertical axis are −3.49 and 6.98 respectively.

ures against physical values of the stimulus rather than against JND's which actually constitute another response measure.

We must question whether each of the mean action potential figures is merely a combination of occurrences and nonoccurrences, in different proportions, of responses which are all about the same size. This may be resolved into the form: Is the distribution of action potentials, accompanying key pressing and non-pressing, unimodal or bimodal? If bimodal, then a high potential would probably indicate an overt response, and a low potential absence of an overt response. A distribution of action potential measures was therefore plotted in Fig. 2.

Figure 2 is a frequency plot of Series III action potential responses measured in log microvolts and expressed as deviations from equated means of the different duration groups in Series III, the experimental series. This distribution could hardly represent a dichotomy of response—no response. Instead it shows responses of varying magnitude to be present whether they are overtly manifest or not. In these figures, there can be only a small quantitative difference between responses which are forceful enough to overcome the resistance of the key and responses which are not. (One of the authors has reported (6) evidence of a dichotomy of responses at the stimulus threshold. This, of course, is a different matter, since stimuli in the present study are well above absolute threshold.)

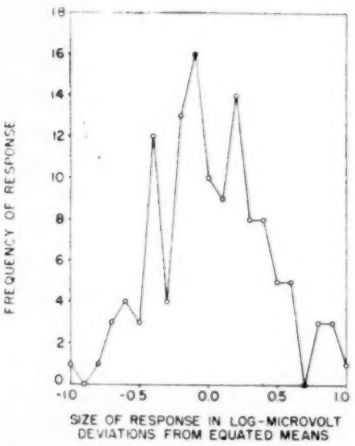

FIG. 2. Frequency plot of Series III action potential responses measured in log microvolts and expressed as deviations from equated means of the different duration groups

As a further test of this notion of continuity, we may raise the following question: If the distribution of log microvolt differences for each group is normal, and if we can find a log microvolt difference value which is critical for key-pressing, will the per cent of readings above this value agree with the per cent of actual key pressings?

The 2-sec. group was used to establish the critical value for key-pressing. In this group, key-pressing occurred 76 per cent of the time. In the normal probability table, this corresponds to an abscissa value of −.72 which, in our distribution of log microvolt differences, corresponds to −.23. Dividing each of the distributions of readings of the other groups at this critical pressing value, we found the number of sigma units this value was from the mean of each group; using for each group the sigma peculiar to it, we determined from the probability table what proportion of the whole distribution would lie above it. These proportions would be the proportions of key pressings we should expect on the basis of the continuity hypothesis. The plot of these in Fig. 3 shows that they agree very well with the per cent of actual key pressings. (The two things are, of course, identical by definition for the 2-sec.

group.) So we find that the continuity hypothesis is further confirmed. For each stimulus there is a mean response which falls lower as the stimulus distance increases, leaving a smaller and smaller proportion of the distribution exposed, as it were, above the overt response threshold.

The continuity we are discussing is the continuity within the distributions at each stimulus value. The continuity of the mean response value as a function of the stimulus duration is another question. Whether these decline in a practically continuous fashion or in large jumps could be decided only by more detailed exploration of the stimulus continuum.

Within the present experimental situation, there appears to be a physiological process which varies in intensity with distance of tonal test stimulus from tonal training stimulus along the dimension of duration. This physiological process manifests certain of the properties required of "habit strength" in this situation. Our physiological process most resembles "reaction potential" in Hull's theory. Other things being equal, this is said to vary with "habit strength." If we assume a constancy of "stimulus dynamism" and other factors (**11**), then the magnitude of "reaction potential" should indicate "habit strength." We have used the normal curve relating responses and "reaction potential" rather than the leptokurtic variation Hull has more recently favored.

It is understood that the muscle action potential response cannot be completely identified with the construct "reaction potential" on this evidence, for the two may not share other properties. In fact, it is doubtful whether our responses can qualify under Hull's formal definition, for we have a different sort of stimulus variation from those formally specified (**11**). If the equation specified for intensive variation be applied to our gradient data, it produces a fit rather less exact, if anything, than our straight line.

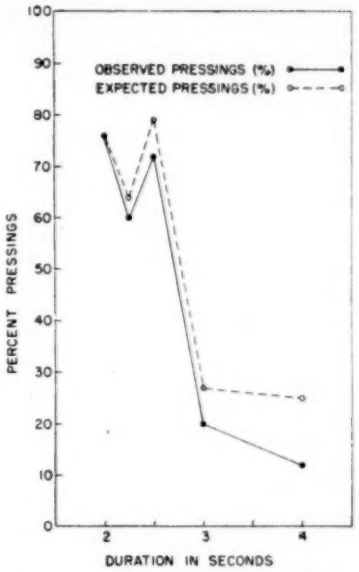

FIG. 3. Comparison of per cent of observed key-pressings with per cent of key-pressings "expected" from a log microvolt difference criterion in Series III

SUMMARY

1. The problem of this study was to investigate whether there are non-overt muscular responses accompanying a stimulus generalization gradient, as well as occasional overt responses.

2. The control series instructions to press a key at the end of every tone resulted in no systematic difference in response, measured by electromyographic technique, with various stimulus durations.

3. In the experimental series, after practice in key pressing to a 2-sec. tone, instructions were to respond only

to a signal like the practice tone. Results showed a decreasing response, with increasing stimulus duration, in the muscle action potentials and in overt pressing.

4. The muscle action potential responses form a unimodal distribution indicating that overt and nonovert responses are a single function.

5. By treating the action potential responses at the various stimulus durations as normal distributions, and by locating a "critical pressing value" in the first of these, it was possible to predict, very closely, the per cent of key pressings for the others.

6. We conclude that there are responses which form a stimulus generalization gradient, these being only occasionally (when they are large enough) manifest as overt responses. The relation of these responses to certain Hullian constructs is discussed.

(Manuscript received January 10, 1951)

References

1. Czehura, W. S. The generalization of temporal stimulus patterns on the time continuum. *J. comp. Psychol.*, 1943, **36**, 79–90.
2. Davis, R. C. Methods of measuring muscular tension. *Psychol. Bull.*, 1942, **39**, 329–346.
3. Davis, R. C. The design and testing of multiple amplifiers for action potential recording. *J. exp. Psychol.*, 1943, **32**, 270–274.
4. Davis, R. C. An integrator and accessory apparatus for recording action potentials. *Amer. J. Psychol.*, 1948, **61**, 100–104.
5. Davis, R. C. Responses to 'meaningful' and 'meaningless' sounds. *J. exp. Psychol.*, 1948, **38**, 744–756.
6. Davis, R. C. Motor responses to auditory stimuli above and below threshold. *J. exp. Psychol.*, 1950, **40**, 107–120.
7. Hovland, C. I. The generalization of conditioned responses: I. The sensory generalization of conditioned responses with varying frequencies of tone. *J. gen. Psychol.*, 1937, **17**, 125–148.
8. Hovland, C. I. The generalization of conditioned responses: II. The sensory generalization of conditioned responses with varying intensities of tone. *J. genet. Psychol.*, 1937, **51**, 279–291.
9. Hovland, C. I. The generalization of conditioned responses: III. Extinction, spontaneous recovery, and disinhibition of conditioned and of generalized responses. *J. exp. Psychol.*, 1937, **21**, 47–62.
10. Hovland, C. I. The generalization of conditioned responses: IV. The effects of varying amounts of reinforcement upon the degree of generalization of conditioned responses. *J. exp. Psychol.*, 1937, **21**, 261–276.
11. Hull, C. L. Behavior postulates and corollaries—1949. *Psych. Rev.*, 1950, **57**, 173–180.
12. Humphreys, L. G. Generalization as a function of method of reinforcement. *J. exp. Psychol.*, 1939, **25**, 361–372.
13. Lindquist, E. F. *Statistical analysis in educational research.* New York: Houghton Mifflin, 1940.
14. Razran, G. H. S. Stimulus generalization of conditioned responses. *Psychol. Bull.*, 1949, **46**, 337–365.
15. Roush, R. G. Tone burst generator. *Electronics*, 1947, **20**, 92–96.

LATENT LEARNING IN THE SOPHISTICATED RAT[1]

BY ELIZABETH FEHRER

Brooklyn College

The studies of latent learning in the laboratory rat that have been published to date have made use of naive animals. As there is, however, evidence that naive and sophisticated animals may learn in different ways (**4, 5**), it seems appropriate to repeat one of the standard latent learning experiments using animals that have had previous laboratory experience.

In the typical latent learning experiment the rat is expected to learn the location of maze paths (**1, 3, 10, 16**) or objects such as food pellets (**2, 6, 7, 8, 9, 12, 13, 14, 17, 18**) in the absence of any obvious present need for such knowledge. Latent learning is, therefore, learning without reinforcement. That such learning can occur has already been shown and attempts have been made to discover the facilitating factors.[2] It has been shown, for example, that the drive state of the animal during the training period is important, weak irrelevant drives permitting the formation of cognitions concerning unneeded objects (**7, 9, 12, 13**) whereas strong alien drives hinder or prevent such learning (**2, 6, 8, 9, 13, 14, 17**). Forcing of turns was found to be unfavorable to cognition formation (**18**). Studies of other factors have yielded inconsistent results (**15**).

An as yet unexplored factor is that cognition formation may be a function of previous experience with the to-be-cognized object. The test of this hypothesis is the purpose of the present study.

It is common human experience to continue to notice things once needed after the need is gone. After searching for an apartment for months and finding one, one may continue for some time to notice apartments that appear to be vacant. After looking up the meaning of an apparently new needed word, one seems to find the same word rather often in casual reading. It seems reasonable to assume that old need systems, even though no longer in a state of tension, may exert a selective function in perception for some time.

If is of course assumed that the effect on perception of a satisfied need will be less than that of an active need. Lewin has interpreted the results of the interrupted task experiments to show that trace systems under tension are more apt to influence memory and future behavior (e.g., resumption) than trace systems corresponding to tasks in which the need to complete has been resolved. It is not known for how long trace systems not under tension can influence perception and behavior but it is possible that such an influence may last for a considerable period of time. Thus, Gestalt psychologists have interpreted errors in perception in terms of assimilation of present process to stable trace systems, and the organization and patterning of ambiguous material have been similarly explained. Trace systems should also exert a selective influence and thus determine which objects will be noticed when many are present.

[1] The writer is deeply indebted to Mymon Goldstein and John Grossberg for their assistance with the experimental work.

[2] In view of Thistlethwaite's excellent recent review (**15**), no attempt will be made to summarize the results of previous studies.

None of the existing latent learning experiments have been designed to test this last hypothesis. The rats that have run in T-mazes to date have all been naive at the beginning of the experiment. They have presumably never strongly needed food or water and have certainly never learned to obtain either by their own efforts. When thirsty they may not notice food as they possess no strong trace systems created by earlier unsatisfied need for food. It is conecivable that if less naive animals had been used (i.e., animals that previously had to work for food) such animals would cognize food even when run very thirsty. In other words, such earlier experiences might lower the threshold for food perception in the presence of an alien drive.

The hypothesis to be tested in the present experiment, therefore, is that rats will notice food when not hungry provided that they have needed and have had to work for food in the past. It is further considered possible that such sophisticated rats may cognize food even when running under an intense thirst drive. It is this last situation that will be explored in the present experiment, although on the basis of previous studies it represents the most unfavorable condition for the occurrence of latent learning.

The present study comprises three experiments. The evidence for latent learning in the first experiment was not clear. As the rats used were rather nervous, it seemed desirable to repeat it with less nervous animals. More extensive pretraining also seemed desirable.[3]

[3] Additional impetus to a continuation of the experiment was given by Prof. E. C. Tolman's statement in an address at the Kurt Lewin Memorial Award Meeting, Denver, 1949, that positive evidence of latent learning had been found under apparently similar circumstances in a University of California study.

Experiment I

Procedure

Experimental design.—Two groups of naive rats who previous to the experiment had never experienced great hunger or thirst were treated in the following manner: After preliminary handling and establishment of maintenance schedules, Group H was given the experience of needing food and working for it while the other group, Group T, never experienced food deprivation. In order to equalize adaptation to experimental procedures before T-maze training was begun, Group T was run to water under thirst motivation in the same manner in which Group H was run to food.

Both groups then ran a T-maze with water on both sides and food on one under thirst motivation, as in the study by Kendler and Mencher (8). Finally, all *S*s were run under hunger motivation in the T-maze.

The need for control groups with the same pretraining experiences but with learning in the T-maze with water on both sides and no food was rejected because of the consistency of results found by other investigators, namely that there is no difference in the test trial behavior of rats who have and who have not been stimulated by food while they were motivated for water.[4]

Subjects.—Twenty-four white rats, 18 male and 6 female, approximately 75 days old at the beginning of the experiment, were used. These were stock rats from the Brooklyn College Biology Department. They seemed to be rather nervous animals. They were slow in settling down to eat or drink in the preliminary trials. The swinging doors in the maze bothered them for a long time.

Apparatus.—A variable-unit maze was built into the pattern shown in Fig. 1. For pretraining, maze units were inserted as blocks to close off the arms of the T, and *S*s were run to food or water at the end of the straight alley. A black curtain was placed between the blocked choice point and the incentive. The water fountains used in the maze were similar to those in the living cages. The food was the same Purina laboratory chow that constituted the regular diet. It was placed on the floor of the maze in piles of three or four pellets.

For T-maze training the straight alley was blocked off at the choice point. Black curtains were placed midway between the choice point and the incentives. Suspended swinging doors at the choice point were lowered behind the *S*s

[4] At the time this experiment was performed no evidence of latent learning had been reported in studies using the above procedures but without extensive pretraining.

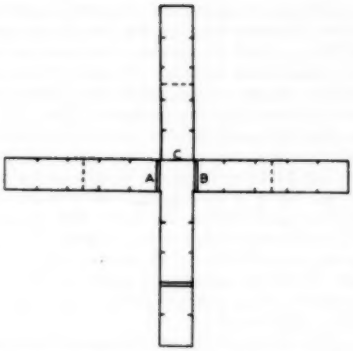

FIG. 1. Maze used in Exp. I. Double lines represent swinging doors. Dotted lines represent curtains. During pretraining, blocks replaced swinging doors at *A* and *B*. During training a block was placed at *C*.

after they had completely turned into one of the alleys.

The maze was covered with a very coarse wire mesh thus permitting *S*s to obtain good extra-maze cues. A ceiling light to the right of the center of the maze was always turned on while *S*s were in the maze.

Pretraining.—After three days of handling, all *S*s were given six days' preliminary training on the straight alley. One trial was given on the first day; four on each of the subsequent five days. Group H (20–22 hr. deprivation) was run to food; Group T (20–22 hr. deprivation) was run to water. Water was always present in the living cages of Group H and food in the cages of Group T. After the last preliminary training trial, large amounts of food were put in all cages and water was removed after 2 hr. so that all *S*s would be satiated for food and under 22-hr. water deprivation on the first run in the T-maze.

Hoarding test.—In order to determine whether the preliminary training caused the groups to differ in their tendency to notice food, a test for hoarding was made just before the *S*s were given their first run in the T-maze. All *S*s were now thirsty but had large piles of food in their cages. Each *S* was offered three pellets of food, one at a time. Of the 12 previously hungry *S*s, 11 hoarded the food avidly, taking it from *E*'s hand and running back to place it on the pile of food at the rear of the cage. None ate any of the food. Of the 12 previously thirsty *S*s, only one accepted the food pellets, the others seemingly paying no attention to them.

T-maze training.—Each *S* was given four trials a day for seven days in the T-maze under a 20–22 hr. thirst drive. Six *S*s were run in rotation, the inter-trial interval for a rat being never less than 10 min. Two filled water bottles were at the end of each arm of the T. The orifice of each bottle on the left side was covered with a food pellet which had to be pushed off before *S* could drink. A pile of food on the floor beneath the bottle required that *S* stand on the food in order to reach the water. No rat was observed eating on any trial.

The first two trials on each day were free and the last two forced by locking the suspension door at the entrance to one of the alleys. Trials were forced so that *S* would enter each alley twice on each day. Forced trials were arranged in a double alternation pattern, i.e., if *S* chose R and then L on the free trials, the forced trials were in the sequence L and R. The *S*s were allowed to drink for 10 sec. on each trial. At the end of the experimental session they were returned to their home cages and allowed to drink freely for 2 to 3 hr.

Latent learning test.—After the last training trial the *S*s were kept on 22-hr. hunger motivation, with water continuously present in the cages. Four free runs a day were given for four days, with the noncorrection method. The *S*s were allowed to eat 15 sec. on each trial in which they turned left. If they turned right, they were removed after 15 sec.

Results and Discussion

The data for T-maze training and testing trials are presented in Table I and Fig. 2. In Fig. 2 is shown the number of animals turning left (towards food) on the two free daily trials each day during the training period and on the four trials each day during the testing period. Table II shows the mean number of left turns

TABLE I

MEAN FREQUENCIES OF LEFT TURNS IN EXP. I

Group	*N*	During 14 Training Trials		During 16 Test Trials	
		Mean	*SD*	Mean	*SD*
H	12	4.42	2.73	12.83	1.34
T	12	5.00	3.19	11.75	1.59

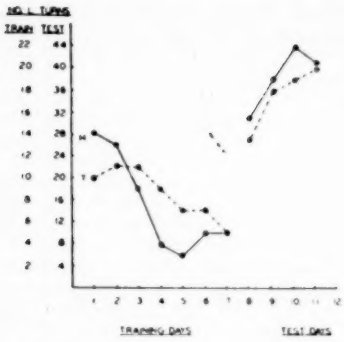

FIG. 2. Number of left turns on each training day (two free trials a day), and on each test day (four trials a day), for Groups H and T

for each group during the training and during the testing periods.

From Fig. 2 it may be seen that the *Ss* learned during the training period to avoid the side of the maze that required pushing the pellet off of the bottle before drinking. This can readily be explained by Hull's principles of gradient of reinforcement and reactive inhibition. This avoidance tendency was as strong in Group H as in Group T, since the mean difference in frequency of left turns throughout training (Table I) is not significant.

On the first test trial, the most clear-cut measure of latent learning, only three *Ss* in each group turned left, thus giving no indication of latent learning (three and four *Ss* in Groups H and T had gone left on the last training trial), and no indication of differential latent learning.

The second test of latent learning, speed of learning the location of food when hungry, showed that, although Group H turned towards food more often than Group T, the difference in mean number of left turns (Table I) does not meet the accepted tests of significance ($p = .10$).

It should be pointed out that even if the obtained difference between the two groups were reliable it could be accounted for on grounds other than latent learning. The group with preliminary hunger training might have learned to perform more effectively under this drive. Consequently Group T that had never before learned under hunger motivation might have had a learning handicap when run hungry in the test trials. There is no experimental evidence on this general problem. We know that animals improve in their ability to learn mazes. But we do not know whether early learning under one drive facilitates subsequent learning under the same drive to a greater extent than later learning under a different drive.[8]

Although the results of this experiment show no clear-cut difference between the two groups of *Ss* with different preliminary experiences, they do not rule out the possibility that latent learning may have taken place in both groups. To test for this, control groups would have been needed which did not encounter food in the training trials. As has been pointed out, however, previously reported studies show no evidence of latent learning in groups treated like our Group T.

EXPERIMENT II

Procedure

This experiment differed in several major respects from Exp. I. First, a control group seemed desirable. Second, it was believed that more extensive preliminary training might yield significant differences between groups with different pretraining experiences. And third, it was believed that less nervous rats might show latent learning more readily if it can be obtained by this experimental technique. However, the general plan was very similar to that of Exp. I. Group HF was comparable to Group H in Exp. I; Group TF was comparable to Group T in Exp. I; and the control group for Group HF, Group HP, was one in which the *Ss* were run hungry to food during pretraining, but in the T-maze

[8] Although there is no evidence on this question for general practice effects, there is a good deal of evidence showing that specific skills learned under one motive or drive may not be readily available when needed to solve problems under other motivating conditions. To cite an extreme example, Schneirla (11) found that ants that have learned a maze path from home to a food supply (when the drive to forage was presumably dominant) did not avail themselves of this skill when confronted with the identical maze path under the motivation to take the food back to the nest.

training trials they found wads of paper about the size of the food pellets, instead of the food, on the orifices of the water bottles on the left side of the maze. Also, a pile of wadded paper balls replaced the food pellets on the floor. The performance of this control group on the test trials should show whether latent learning was occurring in Group HF.

Subjects.—The *Ss* were 18 male Wistar rats aged 70–80 days at the beginning of the experiment. Unlike the *Ss* in the first experiment they were not easily disturbed by the suspension doors and all learned in a few trials to push open the door at the entrance to the maze. They also seemed to run more consistently and settled down to eating and drinking more rapidly in the preliminary training. These *Ss* were divided equally among the three experimental conditions.

Pretraining.—All groups were given far more intensive pretraining than the *Ss* of Exp. I. After three days of handling and establishment of maintenance schedules, all *Ss* were given three to four trials a day for six days in a straight alley. Following this they were given four trials a day for five days in a five choice-point alley maze equipped with black curtains. The correct turns on this maze were straight, right, left, left, right. Neither the crucial initial nor final turns were to the left so that no strong left-turning tendencies would be built up here which might complicate the analysis of the latent learning tests. Finally, two to four trials a day were given for four days in a modified open alley maze. In this maze the entrance was at the middle of one side and the exit to the food chamber at the middle of the opposite side. Throughout these tasks Groups HF and HP ran for food on a 20–22 hr. hunger drive, and Group TF ran for water on a 20–22 hr. thirst drive.

T-*maze training.*—The **T**-maze used here had a stem ten maze units in length whereas in Exp. I the length was five units. In order to provide differential secondary cues at the choice point the curtain hiding the incentive on the right was black, the one on the left side white. Each *S* was allowed to drink for 15 sec. before being removed from the maze. Group HP found wads of paper instead of food on the left side. Aside from the above differences, the procedure was identical with that followed in Exp. I.

Latent learning test.—As in Exp. I all *Ss* were on 22-hr. hunger motivation during the test trials. Food was on the left for all groups. All *Ss* were given four free trials a day for five days. Unlike Exp. I, a correction method was used in these test trials. If *S* turned right at the choice-point he was allowed to retrace and enter the left side. After *S* had fully entered the left side, the door behind him was closed. On each trial *S* was allowed to eat for 30 sec. In reporting turns for the test trials, a turn is recorded as left only when this was *S*'s first choice at the choice point.

TABLE II

MEAN FREQUENCIES OF TURNS TOWARDS FOOD SIDE IN EXP. II AND EXP. III

Group	*N*	During 14 Training Trials		During 20 Test Trials	
		Mean	*SD*	Mean	*SD*
Exp. II					
HF	6	5.50	2.63	16.17	2.27
HP	6	5.50	2.22	14.67	1.60
TF	6	4.17	1.57	12.67	2.36
Exp. III					
H_2	6	2.83	1.86	12.83	1.95
T_2	6	3.67	1.37	10.83	1.34
Exp. II+ III					
HF + H_2	12	4.17	2.64	14.50	2.69
TF + T_2	12	3.92	1.50	11.75	2.13

Results and Discussion

Table II shows the mean number of left turns for each group during the training and testing periods. The total frequencies of left turns on the training and test days are shown in Fig. 3.

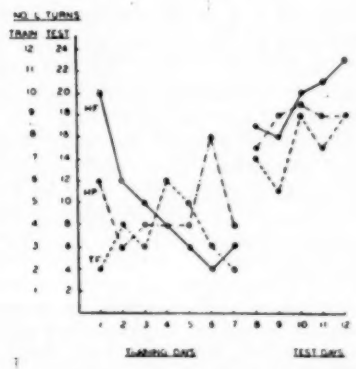

FIG. 3. Number of left turns on each training day (two free trials a day), and on each test day (four trials a day), for Groups HF, TF, and HP.

During the T-maze training trials, the tendency to avoid the left side developed markedly only in Group HF, as is shown in Fig. 3. However, none of the differences between groups in frequency of left turns during all training trials, as shown in Table II, is significant beyond the .30 level.

On the first test trial 3, 2, and 3 *Ss* turned left in Groups HF, TF, and HP, respectively. On the last training trial the comparable frequencies were 2, 1, and 2. Although none of the differences are significant because of the small number of cases it is at least apparent that Group HF showed no marked tendency to turn towards food on this crucial trial as compared with Group TF. There is also no obvious evidence of superiority of the two experimental groups over the control group.[6]

Although the rats of Group HF were not superior to the others on the first test trial, they did learn the location of food more rapidly than either of the other groups. The relevant data appear in Table II. Group HF was superior to Group TF in number of correct (left) turns in the 20 test trials. This difference is significant at the $.05 > p > .02$ confidence level. As shown in Fig. 3, the superiority of Group HF over Group TF was consistently maintained throughout the 20 trials of the testing period.

Group HP learned the location of food somewhat more slowly than Group HF and somewhat more readily than Group TF. The observed differences, however, are not statistically significant.

Although the above analysis shows that Group HF learned the location of food under hunger motivation significantly faster than did Group TF, the interpretation of these findings is not entirely clear, especially when the results for the control group are noted. The control group had no opportunity to learn latently that food was present on the left side of the maze, except through cognized food odor or crumbs. Still, on the critical first test trial they turned left as often as either of the other two groups and during the test trials they showed no reliable learning handicap. Bearing in mind the data for the control group, the significant difference between the performance of Group HF and Group TF can be interpreted in two alternative ways.

1. Group HF showed latent learning whereas Group TF did not, the evidence being the faster test trial learning of Group HF. Here absence of any latent learning on the part of Group TF is shown by the fact that they did not learn reliably faster than the control group in the test trials. This interpretation, of course, supports the initial hypothesis that latent learning of objects not needed at the moment is a function of previously experienced need for those objects.

2. However, a different explanation already mentioned in the discussion of Exp. I is also tenable. It is possible that early learning experience under one drive may facilitate subsequent learning under the same drive more than subsequent learning under a different drive. Here it must be remembered that the initial test trial did not differentiate the two experimental groups. The difference between them appeared only on later trials. The fact that the control group which also had had early practice in learning under hunger motivation learned the food location in the test trials faster (but not significantly faster) than Group TF could support this hypothesis.

Experiment III

In this experiment two additional groups of six rats each, Group H2 and Group T2, were trained under conditions very much like those for groups HF and TF in Exp. II. These rats were Wistar stock rats similar to those used in the preceding experiment.

Procedure

Pretraining.—Pretraining was less extensive than in Exp. II but more thorough than in Exp. I. After three days of handling and establishment of maintenance schedules, the *Ss* were given four trials a day for eight days in a straight alley equipped with a curtain placed between the entrance and the incentive. For Group H2 the incentive was food; for Group T2 it was

[6] When the HP group was run, the food pellets were removed and paper wads substituted. The smell of food and minute crumbs undoubtedly lingered on this side of the maze but there were no visable food pellets to be cognized.

water. The animals were run after 20–23 hr. of deprivation. Following this, *Ss* were given one trial a day for five days followed by two trials a day for four days in a five choice-point alley maze. The initial and final turns were to the left.

T-maze training and latent learning test.—The T-maze training and the testing procedures were identical with those of Exp. II with the single exception that the food was on the right side.

Results and Discussion

The results of Exp. III are presented in Table II and Fig. 4.

During T-maze training these two groups showed a far greater tendency to avoid the food side than was evident in the two preceding experiments. However, the two groups did not differ significantly in over-all right-turning tendency during the training trials.

On the first latent learning test day (Fig. 4) the *Ss* of Group T2 turned right more frequently than did the *Ss* of Group H2. On the four succeeding test days, however, *Ss* of Group H2 turned right more often. The difference between the mean number of right turns for all 20 test trials for these groups is significant at only the .10 level of confidence with 10 *df*.

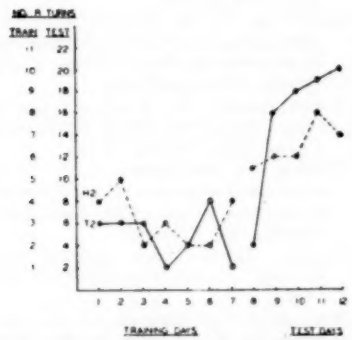

FIG. 4. Number of right turns on each training day (two free trials a day), and on each test day (four trials a day), for Groups H2 and T2

The difference between these two groups on the test trials is greater than the difference found in Exp. I but smaller than that of Exp. II. All differences are in the predicted direction and the size of the difference increases with the amount of pretraining.

If all three H groups and all three T groups could be combined, the differences would probably be more clearly significant. In Exp. I, however, the latent learning testing procedure differed in two respects from that used in the two later experiments. First, a noncorrection method was followed and second, only 16 test trials were given. The test procedures for Groups HF and H2, and for Groups TF and T2 in Exp. II and III were identical. If comparisons are made between the 12 H and the 12 T animals in these last two experiments, the difference on the latent learning test is significant between the .02 and .01 confidence levels. The data are presented in Table II.

SUMMARY

Three experiments were performed to test the hypothesis that latent learning will occur when the object to be learned latently has been needed and worked for in the past. In each experiment groups of rats that had experienced hunger were superior in one of the standard tests of latent learning to groups of rats who had never been hungry. After the opportunity to notice the location of food when thristy, the rats previously trained to run for food learned to turn to the food faster than rats without that experience. The difference was significant at the .10 level in Exp. I, at the .05 level in Exp. II in which the pretraining experiences were most extensive, and at the .10 level in Exp. III. It was significant between the

.02 and .01 levels when the data in Exp. II and III were combined. On the crucial initial test run, however, the groups at no time differed significantly. This latter criterion of latent learning therefore gave consistently negative results.

In comparing the speed of the previously hungry and thirsty rats in learning to locate food it was pointed out that the greater speed of the former may not be a crucial test of latent learning. Before this criterion can be safely used with an experimental design like the present one we need to know whether early practice under one drive transfers as readily to learning new problems under a different drive as under the same drive.

The experiments reported here were performed under conditions that were not favorable for testing the hypothesis. First, the thirst drive used during training was very strong. If the animals had been run after a shorter period of deprivation they might have noticed food more readily. Second, latent learning may be more apt to occur when a contemporaneously demanded goal object is not present. The fact that water was to be found during the training trials might have lessened the cognition of food. An experimental arrangement in which water is present on one side only might have yielded different results even though the need for forcing all later turns towards the food side in this arrangement has obvious disadvantages.

(Manuscript received February 3, 1951)

References

1. Blodgett, H. C. The effect of the introduction of reward upon the maze performance of rats. *Univ. Calif. Publ. Psychol.*, 1928, **4**, 114–134.
2. Grice, G. R. An experimental test of the expectation theory of learning. *J. comp. physiol. Psychol.*, 1948, **41**, 137–143.
3. Haney, G. W. The effect of familiarity on maze performance of albino rats. *Univ. Calif. Publ. Psychol.*, 1928, **4**, 319–333.
4. Harlow, H. F. The formation of learning sets. *Psychol. Rev.*, 1949, **56**, 51–65.
5. Karn, H. W., and Porter, J. M. The effects of certain pre-training procedures upon maze performance and their significance for the concept of latent learning. *J. exp. Psychol.*, 1946, **36**, 461–469.
6. Kendler, H. H. An investigation of latent learning in a T-maze. *J. exp. Psychol.*, 1947, **40**, 265–270.
7. Kendler, H. H. A comparison of learning under motivated and satiated conditions in the white rat. *J. exp. Psychol.*, 1947, **37**, 545–549.
8. Kendler, H. H., and Mencher, H. C. The ability of rats to learn the location of food when motivated by thirst—an experimental reply to Leeper. *J. exp. Psychol.*, 1948, **38**, 82–88.
9. Meehl, P. E., and MacCorquodale, K. A further study of latent learning in the T-maze. *J. comp. physiol. Psychol.*, 1948, **41**, 372–396.
10. Reynolds, B. A repetition of the Blodgett experiment on 'latent learning.' *J. exp. Psychol.*, 1945, **35**, 504–516.
11. Schneirla, T. C. Motivation and efficiency in ant learning. *J. comp. Psychol.*, 1933, **15**, 243–266.
12. Seward, J. P. An experimental analysis of latent learning. *J. exp. Psychol.*, 1949, **39**, 177–186.
13. Spence, K. W., and Lippitt, R. O. "Latent" learning of a simple maze problem with relevant needs satiated. *Psychol. Bull.*, 1940, **37**, 429.
14. Spence, K. W., and Lippitt, R. O. An experimental test of the sign-gestalt theory of trial and error learning. *J. exp. Psychol.*, 1946, **36**, 491–502.
15. Thistlethwaite, D. A critical review of latent learning and related experiments. *Psychol. Bull.*, 1951, **48**, 97–129.
16. Tolman, E. C., and Honzik, C. H. Introduction and removal of reward and maze performance in rats. *Univ. Calif. Publ. Psychol.*, 1930, **4**, 257–275.
17. Walker, E. L. Drive specificity and learning. *J. exp. Psychol.*, 1948, **38**, 39–49.
18. Walker, E. L., Knotter, M. C., and DeValois, R. L. Drive specificity and learning: the acquisition of a spatial response to food under conditions of water deprivation and food satiation. *J. exp. Psychol.*, 1950, **40**, 161–168.

DARK ADAPTATION AND THE HUMPHREYS RANDOM REINFORCEMENT PHENOMENON IN HUMAN EYELID CONDITIONING[1]

BY DAVID A. GRANT AND HAROLD W. HAKE[2]

University of Wisconsin

The purpose of this experiment was to investigate the effect of dark adaptation and varied inter-trial interval upon the Humphreys random reinforcement phenomenon in eyelid conditioning.

Humphreys' report of heightened resistance to extinction of the eyelid CR following 50 per cent random reinforcement as compared with 100 per cent reinforcement (**6**), was one of the most important conditioning findings of the late 1930's. More than earlier investigations of partial reinforcement, this and later excellent researches of Humphreys (**7, 8, 9**) initiated widespread theoretical and experimental effort (**10**).

In the course of related research Grant, Riopelle, and Hake (**5**) obtained extinction curves following 50 per cent random reinforcement which showed precipitous drops in contrast to the gradual decrements reported by Humphreys. It was thought that the difference in shapes between the Wisconsin extinction curves and those of Humphreys could be accounted for in terms of various differences in procedure, and, in view of the great significance of Humphreys' phenomenon, it was desirable to test this conjecture.

It was presumed that the critical difference between Wisconsin procedures and those of Humphreys was that Wisconsin *Ss* were maintained in a light-adapted state where Humphreys' *Ss* were permitted to become dark-adapted during the course of the experiment. The Wisconsin procedure largely avoids progressive sensitization of the β-response of the eyelid to light, a phenomenon discovered shortly after Humphreys' results had been published (**3**). If present, the β-responses could easily be confused with CR's and, in addition, could seriously affect the course of acquisition and extinction of the CR (**4**), so that Humphreys' findings could conceivably be largely artifactual. In the present study, Humphreys' 50 per cent random reinforcement and his 100 per cent massed procedures were carried out, with slight modifications, under dark- and under light-adapted conditions. Also Humphreys used a constant 30 sec. interval between trials. This was contrasted with the effect of a variable time interval such as that used by Grant, Riopelle, and Hake. The present experiment, therefore, was based on a tri-factorial design, 50 vs. 100 per cent reinforcement, light vs. dark adaptation of *Ss*, and constant vs. varied inter-trail interval.

Apparatus and Procedure

A modified Dodge photochronograph controlled administration of stimuli and recorded responses as in previous studies cited (**3, 4, 5, 6**). For *Ss* who were permitted to become dark-adapted, the stimulus field, a 10-cm. circular milk-glass window, 60 cm. directly in front of *Ss* eyes, was held at a pre-stimulus brightness of .02 apparent ft. candles. This was the only visible

[1] This investigation was supported by the Research Committee of the Graduate School of the University of Wisconsin from funds voted by the State Legislature.

[2] Now at the Institute for Cooperative Research, The Johns Hopkins University.

illumination. For light-adapted *Ss* a 30-cm. square white diffusing surface around the stimulus field was illuminated to a brightness of 14 to 35 millilamberts. In addition, the light-adapted *Ss* were exposed for 1 min. to a brightness of 3760 millilamberts at the beginning of each session of the experiment. The CS for dark-adapted *Ss* was an increase in the brightness of the stimulus field from .02 to 20 millilamberts. (This was the same order of magnitude as Humphreys' 15 ft. candles.) For light-adapted *Ss* the CS was a rise in brightness of the stimulus field from 14 to 200 millilamberts.[3] The UCS was a puff of air to the cornea. The CS always lasted .75 sec., and the UCS, when given, followed the offset of the CS by .45 sec. For half the *Ss* the time between trials was held constant at 35 sec. For the remaining *Ss* the time between trials was varied unsystematically from 25 to 45 sec. so as to average about 35 sec.

All *Ss* received 48 training trials on Day 1, and 24 training trials on Day 2. The 24 training trials on Day 2 were followed immediately by an extinction series of 24 unreinforced trials with the light alone. The *Ss* receiving 50 percent "random reinforcement" during the training series were given the CS plus UCS on 50 percent of the trials and the CS alone on 50 percent of the training trials. The order of reinforced and unreinforced trials was random except that there were never more than two reinforced or unreinforced trials in a sub-sequence and each series of six trials contained three reinforced trials.

Experimental design.—The three independent variables: 100 vs. 50 per cent reinforcement; dark- vs. light-adapted *Ss*; and constant vs. varied time intervals, were arranged in all of the eight possible combinations so that an orthogonal tri-factorial design resulted. Ten *Ss* were utilized in each group, so that 72 *df* from *Ss* within groups were available for the basic error estimate.

Subjects.—The *Ss* were men and women students who volunteered from introductory psychology courses. They were assigned to the eight experimental procedures solely upon the basis of the order in which they appeared for the experiment. All *Ss* were instructed to ". . . behave naturally and let their reactions take care of themselves."

Results

Frequency and magnitude data showed essentially similar trends so that frequency data alone will be presented. In order to get data fairly comparable with those of Humphreys, all responses with latencies from .13 sec. to .45 sec. were included in the analysis as CR's, but only one response was read per trial. Thus, although the α-response, or primary reflex to light, was omitted, β-responses with latencies from .13 to .24 sec. were included if present.

The essential findings of the experiment are presented in Fig. 1. Here, the per cent frequency of CR's is plotted against successive six-trial blocks through acquisition and extinction. The effect of constant vs. varied inter-trial interval was found to be virtually nil so that this factor is eliminated in Fig. 1 and in further analysis. Thus each point in Fig. 1 is based on the data of 20 *Ss* or 120 trials and the tri-factorial experimental design was collapsed into essentially a two-factor orthogonal design with 20 *Ss* in each of the resulting four groups.

The curves of Fig. 1 may be compared with Fig. 1 and 2 of Humphreys (6, pp. 146, 148). The per cent frequencies of CR's in the dark-adapted groups of the present experiment are almost exactly the same as the frequencies reported by Humphreys. The chief differences are two; namely, the maximum frequency on Day 1 for the 50 per cent procedure is somewhat less than that found by Humphreys, and on Day 2 the frequency of CR's in the 100 per cent group does not drop quite as much as did the data of Humphreys' 100 per cent group during extinction.

The important results of Fig. 1 are the discrepancies between the curves of the dark-adapted groups and those of the light-adapted groups. During acquisition, the per cent frequency for dark-adapted *Ss* is heightened by

[3] The rise in illumination from 14 to 200 millilamberts in the light-adapted groups cannot be directly compared with the rise from .02 to 20 millilamberts in the dark-adapted groups.

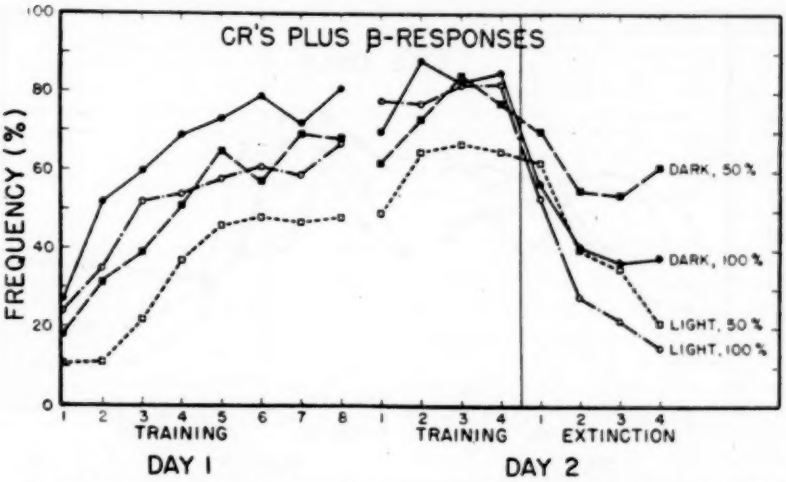

FIG. 1. The per cent frequency of CR's and β-responses plotted for each successive six-trial block during acquisition and extinction for the two 50 per cent randomly reinforced groups and the two groups receiving 100 per cent reinforcement.

the presence of β-responses among the CR's. The same may be said for the extinction trends. The rapid deceleration of the extinction curves for the dark-adapted groups is simply not found in the light-adapted groups. In the latter, the extinction drop is precipitous and deceleration did not take place during the 24-trial series. Apparently, the early deceleration in both the 100 and 50 per cent dark-adapted groups was caused by the presence of β-responses which showed little or no reflex adaptation during the 24-trial extinction series. That this was apparently the case, was indicated when the β-responses (with latencies from .13 to .24 sec.) were omitted from the analysis. The curves of the dark-adapted and light-adapted groups were then virtually overlapping throughout much of acquisition and extinction as is shown in Fig. 2.

The data of Fig. 1 were subjected to the Alexander trend test (1) in order to get the most complete and unified analysis of variance. Following Bartlett (2) the transformation $\theta = \sqrt{X + 0.5}$ was used where X was the original raw frequency.[4] The over-all analyses are summarized in Table I. The error variances are given in parentheses in the last row of Table I. For clarity, the Day 1 acquisition, Day 2 acquisition, and Day 2 extinction data were analyzed separately.

The significant Fs in Rows d, e, f, and g of Table I show that there is variation from S to S in the mean response level and in the rates of acquisition and extinction, respectively; and further, that the over-all acquisition and extinction trends are non-linear and significant. The variation in mean response level and in acquisition and extinction trend between groups is illustrated by the significant Fs in Rows a and b. In all the primary Fs the denominator variance estimate was obtained from *individual deviations from estimation*; but in italics in Rows a and b, secondary F tests (1, p. 540) were made against the variance estimated from *between individual means* (a) or *slopes* (b). From these it would appear (.05 confidence level) that the variation between group means on Day 1 acquisition and

[4] Trend analyses were carried out on both the raw frequencies per six-trial block and on the transformed raw frequencies. The results were essentially the same in all instances as far as the significance levels of the Fs were concerned.

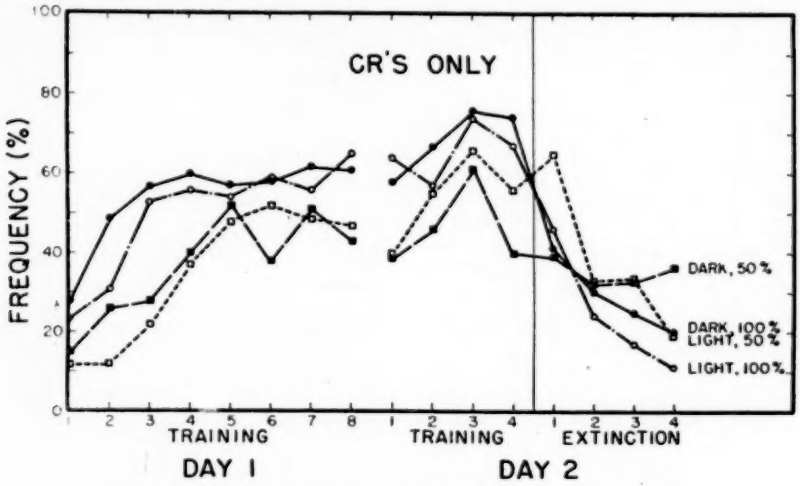

FIG. 2. The per cent frequency of CR's only plotted for each successive six-trial block during acquisition and extinction

Day 2 extinction and the variation between group extinction slopes on Day 2 could not be accounted for by the considerable individual variation revealed in Rows d and e of Table I.

The *between-group means* sums of squares were partitioned into the three orthogonal components due to the character of the reinforcement, the light or dark adaptation, and the reinforcement-adaptation interactions. The *F*'s resulting from this analysis are given in Table II. Rows i, j, and k contain the *F*'s obtained from the corresponding basic error terms (Row h from Table I), and Rows l, m, and n contain the italicized *F*'s obtained from the same numerators but divided there by the *between-individual means* variance estimates (Row 6, Table I). The

TABLE I

SUMMARIES OF ALEXANDER TREND TESTS ON THE TRANSFORMED FREQUENCIES OF EYELID CR'S DURING ACQUISITION AND EXTINCTION

Source of Variation	Day 1, Acquisition		Day 2, Acquisition		Day 2, Extinction	
	df	*F*	*df*	*F*	*df*	*F*
a. Between-group means	3	99.50***	3	44.64***	3	43.48***
		*4.90**		*2.69*		*3.76**
b. Between-group slopes	3	1.94	3	3.06*	3	9.30***
				1.72		*5.19**
c. Group deviations from estimation	18	1.48	6	2.65*	6	1/2.78
d. Between-individual means	76	20.32***	76	16.59***	76	11.57***
e. Between-individual slopes	76	3.76***	76	1.78*	76	1.79*
f. Over-all deviations from linearity	6	10.05***	2	11.28***	2	8.73***
g. Over-all slope	1	463.79***	1	46.87***	1	103.48***
h. Individual deviations from estimation (error)	456	(.0997)	152	(.0403)	152	(.1065)

* Significant at .05 confidence level
*** Significant at the .001 confidence level

TABLE II

*F*s Resulting from the Partition of the Between Group Means Sums of Squares of Table I

Source of Variation	Day 1, Acquisition	Day 2, Acquisition	Day 2, Extinction
	F	*F*	*F*
j. Dark adaptation	143.33***	34.24***	85.63***
k. Adaptation × reinforcement	3.51	13.90***	3.00
l. Random reinforcement	*7.46***	*5.17**	*3.61*
m. Dark adaptation	*7.05***	*2.06*	*7.41***
n. Adaptation × reinforcement	*1/5.79*	*1/1.19*	*1/3.84*

* Significant at .05 confidence level
** Significant at .01 confidence level
*** Significant at .001 confidence level

significant *F*'s show that both random reinforcement and dark adaptation play a considerable role in establishing the pooled frequency of CR's and β-responses. The interaction is significant only on Day 2 acquisition, and there it fails of significance when tested against individual variation (Row n). Random reinforcement significantly depresses the frequency of CR's during acquisition, and dark adaptation significantly raises the response level (except, possibly, during Day 2 acquisition, where the secondary *F* was not significant). During extinction the effect of random reinforcement is slightly ambiguous. Although there appear to be significantly more frequent CR's in the randomly reinforced groups (primary $F = 41.69$), the *F* against individual variation (3.61) fails to attain significance so that the significance of the primary *F* may have occurred by virtue of consistent individual variation. The random reinforcement seems to have an important effect upon the first few extinction trials as is shown in Fig. 1 and 2. The 100 per cent curves drop suddenly whereas the 50 per cent curves show less of an immediate drop. In other words, as noted by Humphrey (6), the frequency of CR's remains relatively high for the first block of extinction trials. The difference between the 50 and 100 per cent groups in initial extinction drop was significant at the .01 level when tested statistically ($t = 2.83$ for 78 *df*).

The sums of squares due to variation in group slopes were also partitioned as was done with the group means, above. This further analysis revealed that the variation in group slopes on Day 2 acquisition could be attributed almost entirely to the random reinforcement. More important, the variation in group slopes during extinction was due almost entirely to dark adaptation which accounted for 2.62 of the total 2.97 sum of squares between group slopes. The other components failed of significance when tested against the basic error terms and hence also failed when tested with variance estimates from the between individual slopes components.

Discussion

The results of the present experiment are clear-cut. Dark adaptation increases the frequency of eyelid responses during both acquisition and extinction. By discarding all responses with latencies less than .25 sec., the β-responses (about 30 per cent of the total in the dark-adapted groups) are eliminated, and the results of the light-adapted and dark-adapted groups become more comparable.

The effects of random reinforcement are more complex. In contrast to Humphreys' findings with frequency data, 50 per cent reinforcement definitely results in depression of the frequency of CR's during acquisition in the present experiment. The frequency data of the present study differ sharply from the magnitude data reported by Grant, Riopelle, and Hake (5). This may be accounted for in part by general differences in magnitude and frequency measures, but further clarification is needed. During extinction the randomly reinforced *S*s give more CR's, and this tendency apparently remains even when the effects of dark adaptation are taken into account. The rapid negative deceleration found by Humphreys to follow 50 per cent reinforcement, however, occurred only in the dark-adapted groups of the present experiment. Negative deceleration remains in Fig. 2 when the β-responses have been eliminated, but it is

apparently primarily an effect of dark adaptation or reinforcement-adaptation interaction, although there is little statistical evidence for the latter. The statistical analysis showed that of the total sum of squares *between-group slopes* during extinction of 2.97, 2.62 (*significant at .001 level*) was due to dark adaptation, and the variation in slope due to 50 per cent reinforcement was not nearly statistically significant ($F < 1.0$).

The main conclusions to be drawn are three: (a) 50 per cent random reinforcement, when sensitized β-responses are controlled, depresses the frequency of eyelid CR's during acquisition; (b) the extreme negative deceleration in Humphreys' extinction data may have been an artifact due to dark adaptation and the attendant sensitization of the β-response of the eyelid to light; and (c) 50 per cent random reinforcement seems to produce some increased frequency of CR's during extinction over and above the effects of dark adaptation. Some ambiguity attaches to this last conclusion because of widespread individual variation, but the results were consistent under both the dark-adapted and the light-adapted conditions.

Summary

The acquisition and extinction of the conditioned eyelid response to light was studied in all combinations of the conditions of dark vs. light adaptation of the *S*s, 50 vs. 100 per cent reinforcement during the training series, and constant vs. randomly varied intertrial intervals, to produce an orthogonal tri-factorial experimental design. Ten *S*s were used in each of the eight groups. The frequency of all eyelid responses with latencies from .13 to .45 sec. (thus including sensitized β-responses) was studied during acquisition and extinction. The constancy of the intertrial interval had no discernible effect and was ignored in the analysis of the data. The principal findings were as follows:

1. Dark adaptation increased significantly the frequency of eyelid responses at all stages of the experiment except, perhaps, during Day 2 training trials. That this was due to the presence of β-responses was indicated by the fact that elimination of the responses with latencies from .13 to .24 sec. made the curves of dark-adapted and light-adapted *S*s almost alike.

2. The frequency of CR's was depressed during training trials by the 50 per cent random reinforcement procedure. This result is not in accord with Humphreys' findings nor with the magnitude data of Grant, Riopelle, and Hake, but is in line with the general results of other partial reinforcement studies.

3. During extinction only the dark-adapted randomly reinforced group showed the sharp negative deceleration obtained by Humphreys. The statistical analysis showed that this effect was due to dark adaptation and not to random reinforcement.

4. There was some indication, supported by the statistical trend analysis, that 50 per cent random reinforcement was followed by greater resistance to extinction, as evidenced by a greater mean frequency of CR's, than was 100 per cent reinforcement. Although this evidence was rendered somewhat ambiguous by the existence of great individual variability, there remained statistical evidence that the initial drop in frequency during extinction is less following random reinforcement than following 100 per cent reinforcement.

These results lead to the conclusion that the rapid negative deceleration found by Humphreys was in part an artifact caused by the progressive sensitization of the β-response during extinction. There remains, however, evidence that Humphreys' report of heightened resistance to extinction of the eyelid CR following random reinforcement is valid. This is shown by the greater frequency of CR's and the slow initial drop in the extinction curves of these groups.

(Manuscript received February 5, 1951)

References

1. Alexander, H. W. A general test for trend. *Psychol. Bull.*, 1946, **43**, 533–557.
2. Bartlett, M. S. The use of transformations. *Biometrics*, 1947, **3**, 39–52.
3. Grant, D. A., and Norris, Eugenia B. Dark adaptation as a factor in the sensitization of the beta-response of the eyelid to light. *J. exp. Psychol.*, 1946, **36**, 390–397.
4. Grant, D. A., and Norris, Eugenia B. Eyelid conditioning as influenced by the presence of sensitized beta-responses. *J. exp. Psychol.*, 1947, **37**, 434–439.
5. Grant, D. A., Riopelle, A. J., and Hake, H. W. Resistance to extinction and the pattern of reinforcement: I. Alternation of reinforcement and the conditioned eyelid response. *J. exp. Psychol.*, 1950, **40**, 53–60.
6. Humphreys, L. G. The effect of random alternation of reinforcement on the acquisition and extinction of conditioned eyelid reactions. *J. exp. Psychol.*, 1939, **25**, 141–158.
7. Humphreys, L. G. Acquisition and extinction of verbal expectations in a situation analogous to conditioning. *J. exp. Psychol.*, 1939, **25**, 294–301.
8. Humphreys, L. G. Extinction of conditioned psychogalvanic responses following two conditions of reinforcement. *J. exp. Psychol.*, 1940, **27**, 71–75.
9. Humphreys, L. G. The strength of a Thorndikean response as a function of the number of practice trials. *J. comp. Psychol.*, 1943, **35**, 101–110.
10. Jenkins, W. O., and Stanley, J. C. Partial reinforcement: a review and critique. *Psychol. Bull.*, 1950, **47**, 193–234.

A NEW TECHNIQUE FOR OBSERVING CONCEPT EVOCATION[1]

BY MELVIN R. MARKS

Personnel Research Section, Adjutant General's Office, U. S. Army

AND

CHARLES K. RAMOND

State University of Iowa

The purpose of this paper is to explore further a new method of quantifying studies of the "higher mental processes." Such studies have two primary aspects: (a) the independent variable, usually known as the stimulus-situation or problem (P); and (b) the dependent variables, usually known as the response-pattern or behavior (B). Marks (1) has suggested that the inadequacy frequently characterizing studies in this area may be traced to the fact that (a) the P chosen is described in a manner not easily relatable to possible variation in B, and (b) the B is reported in terms of anecdotal protocols based either on *E*'s observations, *S*'s introspections, or both.

Some studies successfully quantify B; a few have successfully quantified P; none found by the writers successfully and simultaneously quantify both P and B. Marks (1) showed that when P (*S*'s problem was to find an experimentally-induced error in a square root-determination sequence) was quantified in terms of its elements, i.e., the "givens" of the problem, and B was quantified in terms of *vocalizations* by *S* of such elements, the relationship between vocalizations and problem-solutions was indicated by $r_{tet} = .83$. He found also that when P was presented in both "textbook" and "real-life" situations, the textbook situation was evocative of more vocalizations and more solutions.

This paper extends the method of quantifying P and B to a study of problem-solving involving concept evocation. If we think of concept-evocation as a type of problem, then the concepts which might *possibly* be evoked in the particular situation become the elements of the concept-evocation problem. Then P may be quantified in terms of the number of possible concepts inherent in the situation, and B may be quantified in terms of *S*'s awareness of these concepts (elements). Since awareness is a private datum, it is defined operationally as vocalizations of concepts. It is proposed that, for *S* to form successfully the criterion concept (solve the problem), he must be aware of the elements. The writers believe that such awareness arises as a result of analysis by *S*, and that such analysis may be facilitated or disrupted by the situation in which the problem is set. Specifically, P may be presented to *S* in a spontaneous, loosely-formulated fashion in simulation of a "real-life" situation, or it may be made highly specific in simulation of a "textbook" situation.

Two hypotheses, experimentally

[1] This experiment was performed at Tulane University by the junior author as part of an undergraduate program of honors research. The senior author directed the study and is responsible for the theoretical views here presented and for the preparation of the manuscript in its present form.

testable, stem from the discussion: (a) solving-behavior is positively related to concept-evocation behavior when the latter is measured in terms of vocalization of concepts; (b) a textbook situation will be more evocative of both solving-behavior (solutions) and concept vocalizations than will a real-life situation.

Procedure

The materials consisted of 26 white 3 × 5 in. cards. Upon one side of each of these, two paper figures were pasted. The figures varied as to shape (triangles, squares, and pentagons); size (¾ in. altitude, called "small," and 2 in. altitude, called "large"); color (red, yellow, green, blue, and gray standard art paper); and position (one figure overlapped the other on each of the cards). The *S*'s task was to sort these 26 cards into four separate piles, using a principle which was both *consistent* and *exclusive* as defined in instructions. Since there were three shapes, two sizes, five colors, and two positions, the concept on which correct classification could be based was necessarily complex. It involved the simultaneous use of the simpler concepts, size and position, in the following manner, the numbers in parentheses referring to the piles: (1) large on large; (2) large on small; (3) small on large; (4) small on small.[1]

The *S*s were 163 students from Tulane University and H. Sophie Newcomb College. Eleven of this number participated in a pilot study. The remaining 152 were divided into a real-life situation (RL) group and a textbook situation (TB) group, each of 76 *S*s. All sampling was "accidental" but there was no reason to believe that either of the groups was systematically biased insofar as the particular task was concerned. Each *S* was recruited individually and asked to serve in an experiment which would "test ingenuity." All experimental sessions were individual. With the RL *S*s, the pack of 26 cards was scattered on a small table, and the following instructions read:

"Here is a pack of cards consisting of four different groups. Your task will be to separate these groups. For instance, if I were to give you an ordinary deck of playing cards and ask you to sort them into four groups, you would immediately think of the four suits—spades, hearts, diamonds, clubs; if I asked you to sort them into 13 groups, you would classify them according to rank—twos, threes, fours, and so on. Your task here is similar, and the four classifications you make must be both exclusive and consistent. Exclusiveness means that when you have completed the separation, each card can belong to one and only one group. Playing cards divided into suits form exclusive groups, since no one card can be both a spade and a diamond, or a heart and a club. Consistency means that you must use the same principle of classification throughout the separation. In other words, if I were dividing a deck of playing cards, I would *not* make, say, one pile of spades, then a pile of kings or sixes, then a pile of cards which had blue advertisements on their backs. If I started with suit, I would continue with suit; if I started with rank, I would continue with rank, and so on. There is no catch in this test; there is a definite, logical principle of classification which you may find. When you reach a solution which you think is correct according to the rules of exclusiveness and consistency which I just mentioned, you let me know and I'll stop the watch. One more thing before we start, and this is very important. I would like you to think out loud while you work. Vocalize all your ideas and impressions, no matter how silly or irrelevant they may seem. Just keep up a sort of rambling monologue so that I'll know what you are thinking about while you are separating the cards. Remember, you want to make four piles, four exclusive groups based on some consistent principle. Please begin."

With the TB group, the procedure differed as follows: (a) The test cards were not scattered on the table until after the instructions were read; (b) the instructions were embedded in the context of a story about a fictitious "Bill Smith," but included exactly the same directions as were given the RL group. The story was:

"Bill Smith, a recent college graduate, was one of many who applied to a certain large firm for a highly-paid position. In the process of weeding out the unqualified applicants, a test was given, with the understanding that only those who successfully passed the test could be considered further for the job. When it came Blil Smith's turn to be tested, he was taken to a small room and seated at a table on which a number of cards were scattered. The examiner, sitting across from Bill, read to him the following instructions." (At this point *E* read to *S* the same instructions as were used with the RL group.)

"Bill thought he understood the instructions and turned his attention to the cards. He noted that each card had pasted on it two figures which varied in color, shape, size, and position. Look-

[1] Actually, other exclusive, consistent solutions were possible. However, of the 48 solutions furnished by the 152 *S*s, only one was of a type other than that described above.

ing further, he found that the figures were of five different colors (red, yellow, green, blue, and gray), three different shapes (triangles, squares, pentagons), two sizes (small and large), and that in each case, one figure was pasted over the other." (Here, *E* told *S* that "Bill" was stuck, and asked *S* to offer suggestions as though he were looking over Bill's shoulder giving him hints.)

With the RL group, the watch was started with the phrase, "begin now," and with the TB group it was started with the question, "What would be your first suggestion to Bill?" Each *S*, irrespective of group, was allowed a total of 10 min. The *E* recorded on a suitable form all concepts vocalized, the type of solution, if any, and the type and sequence of concepts. The *E* did answer questions of the type, "Any time limit?" or, "Are there the same number in each group?" He avoided answering questions of the type, "You mean I should put them together by colors?" or, "Do the shapes count?", although the latter questions would be vocalizations of the concepts of color and shape and would be counted as such.

According to the hypotheses, the facilitating effect of the TB situations rests in their impersonalness; consequently, with the TB group, *E* carefully avoided using the second person in communicating with *S*, unless the word "you" was qualified later in the phrase by a tie-up with "Bill." For example, "Is that the solution you think would get Bill the job?" was one question frequently asked by *E* when *S* had arrived at some solution. For the RL group, all instructions were oral; for the TB group, *E* read aloud while *S* followed on a typewritten copy.

Whenever *S* was silent for 30 consecutive seconds, *E* urged *S* to think aloud. A concept was not recorded as having been vocalized until *S* named the *class* rather than the *particular*, i.e., the vocalization, "triangle," was not counted as a concept, whereas "I'm doing it by figures" (referring to the class concept of form) was counted as a vocalization.

Results

The results were of three kinds: (a) solving-behavior (solutions); (b) concept-evocation behavior (vocalizations); (c) relationships between vocalizations and solutions. The writers had intended originally to classify solutions hierarchically, ranging from consistent-exclusive solutions through inconsistent-exclusive, consistent-nonexclusive, inconsistent-nonexclusive, and simple failure to arrive at a solution. However, the rationale for such subtlety of evaluation is doubtful at best. Consequently, the frequencies of solutions given in Table I are for consistent-exclusive solutions versus all others.

TABLE I

Concept Vocalizations per 100 Sec. and Frequencies of Solutions

Group	Solvers			Nonsolvers			Total Group	
	N	Concepts		*N*	Concepts		Concepts	
		Mean	*SD*		Mean	*SD*	Mean	*SD*
TB	32	2.30	.93	44	1.33	.81	1.73	.81
RL	16	1.82	.87	60	1.17	.73	1.44	.74

Vocalizations by RL and TB groups are also given in Table I. The unit adopted is the mean number of concepts vocalized per 100 sec. of observed behavior. The results are reported in terms of rates rather than as frequencies inasmuch as *S*s took varying amounts of time either to complete the task or to relinquish it. An *S* who vocalizes five concepts in 60 sec. and completes the solution obviously demonstrates more "awareness" of problem-elements than does an *S* who vocalizes seven concepts in 600 sec. and fails to arrive at a solution.

Solutions in TB and RL situations.—Of those *S*s in RL situations, 21 per cent successfully solved P, whereas 42 per cent of the TB *S*s were successful. The critical ratio for the difference is 2.80. Since the direction of this difference was predicted, a one-tailed test of significance is appropriate. The difference is clearly significant ($p = .0026$).

Vocalization rates in solvers and nonsolvers.—The mean concepts per 100 sec. for nonsolvers in the RL group was 1.17; for the solvers, 1.82. This difference is significant ($t = 3.00$, $df = 74$, and $.005 > p > .001$ with a

one-tailed test). For the nonsolvers and solvers of the TB group, the corresponding means are 1.33 and 2.30. Again the difference is highly significant ($t = 2.99$, $df = 74$, and $.005 > p > .001$ with a one-tailed test). Solvers vocalized at a significantly higher rate.

Vocalization rates in TB and RL situations.—For the TB group, the mean concepts per 100 sec. was 1.73; for the RL group, 1.44. The TB group vocalized at a significantly higher rate than the RL group ($t = 2.28$, $df = 150$, and $.02 > p > .01$ with a one-tailed test).

Correlations.—The hypotheses from which the investigation proceeded imply positive relationships between (a) TB situations and solutions; (b) TB situations and vocalizations; and (c) solutions and vocalization. Pertinent results are presented most meaningfully in terms of the correlation coefficients listed in Table II. It is interesting that r_{tet} is .85 for vocalizations and solutions. In Marks's (1) earlier study, vocalizations referred to four possible sources of error in a square root problem and solution was the finding of the error. Yet, in that quite different investigation, r_{tet} was .83. It is clear that awareness of elements of a situation as manifested in vocalizations is highly related to successful behavior in that situation, and that the setting of the situation, i.e., TB or RL has a marked effect on both vocalizations and solutions.

Miscellaneous results.—In order to determine whether order and frequency of vocalizations of specific concepts were comparable for TB and RL groups, rank-order coefficients of correlation were computed. For the 13 most used concepts, using as a measure mean order of occurrence, $\rho = .91$ when TB and RL groups were compared. When the measure used was rank of frequency of occurrence, $\rho = .89$. Apparently, although TB and RL situations are significantly different in terms of vocalizations and solutions, they are very similar with respect to order and frequency of concepts used. The three most frequently vocalized concepts were shape (144 vocalizations); color (131); and size (111).

TABLE II

TETRACHORIC CORRELATIONS FOR SELECTED COMPARISONS OF THE EXPERIMENTAL VARIABLES

Comparison	N	r_{tet}
Solving behavior with situations (solutions and TB group "high")	152	.40*
Concept-evocation behavior with situations (above-average vocalization rate and TB group "high")	152	.40*
Concept-evocation behavior with solving behavior (above-average vocalization rate and solutions "high")	152	.85

* It is recognized that r_{tet} is not strictly applicable in the case of the first two correlations shown.

DISCUSSION

The superiority of the TB group in both solving and concept-evocation behavior is clear-cut experimentally and entirely consistent with Marks's (1) earlier finding that a TB situation is more productive of vocalizations of problem-elements and solutions in orthodox problem-solving. One possible explanation of the results of both studies is that the crucial factor is the verbal structure of the situation in which *S* finds himself. Although nominally the groups are in real-life and textbook situations, *quantitatively* the TB group received more instruction than did the RL group, as is, of course, the case in everyday experience. The nature of the instructions for both studies was such that either the elements of the problem or the possible concepts were more accessible

to *Ss* in the TB group. Thus, TB *Ss* might be said to have a "head start" insofar as they were not required to verbalize for themselves either vocally or subvocally. Corollary evidence is available in those studies which demonstrate the facilitative effect of guidance in learning. To summarize this point of view, the language of instruction in problem-solving or concept-evocation studies has a generalizing function—the more you put in, the more you get back. If this point of view be the correct one, then the hypothesis that the RL situation disrupts analysis (and so lessens awareness and vocalizations) is unnecessary. The results are then merely an artifact of the method.

It is felt that the foregoing explanation is not tenable in light of evidence from Marks's (1) earlier study. There, after a 10-min. period of vocalization without special instruction of any kind, both TB and RL groups were furnished with a list of the elements of the problem and told explicitly that the answer to the problem lay in proper use of one of the listed elements. This is verbal instruction carried to the extreme. Under such circumstances, if the point of view summarized above were correct, it would be reasonable to expect that the two groups, although they had differed in number of vocalizations up to the time the list was furnished, would not differ in solutions since each group had been furnished with a complete statement of the optimum results of abstraction, i.e., all of the elements of the problem. Yet, under these circumstances, the TB group produced significantly more solutions.

If the hypothesis that the difference in RL and TB groups is attributable to the additional language-structure of the TB situation is untenable, what other explanation might be offered? A sort of "common-sense" empiricism suggests that RL situations, involving *S* alone, constitute personal problems, and that the situation itself tends to disrupt or inhibit that awareness of problem-elements or possible concepts which are necessary for solution. On the other hand, in this investigation and otherwise, the TB situation is relatively impersonal—*S* is working on someone else's problem, albeit fictitious. In this case, *S*'s analytical powers are relatively unhampered in the search for elements or concepts. We know that people do better in school problems than in real-life problems. Perhaps the academic halls have an atmosphere conducive to analysis. There is other evidence that it is the process of analysis rather than its products which increases the chances of a successful approach to problem-situations. The findings of psychotherapy are clear on this point. The "insight" handed by the therapist to the patient in "package" form is assimilated intellectually rather than emotionally; at least, it produces no stable therapeutic effect. Whatever the implication of such terms may be, it is apparent that guidance without active participation is of little value in the higher mental processes. From this standpoint, the failure of the list of elements to equate RL and TB groups in solutions is understandable. Unless *S* becomes aware of the elements through his own efforts, he is hampered in their combination and application; the inhibiting effect of the RL situation maintains throughout the course of the activity.

Summary and Conclusions

A task which involved the formation of a complex size-position concept as the basis for sorting a set of cards into exclusive and consistent categories was presented to 152 *Ss*. Half of the *Ss*

served in a "real-life" (RL) situation, so characterized because the task was *S*'s own—no other person was mentioned in connection with the task. The other half served in a "textbook" (TB) situation in the sense that the task was one of helping a *described* fictitious person who had been placed in a situation identical with that of the RL group. A total of 10 min. of activity was allowed each *S*, although some were successful in a shorter period, and some relinquished the task without attempting solution. Behavior was quantified in terms of concept-vocalization rate according to pre-set criteria, and records of incidence and kinds of solutions were kept.

Within the limits of the definitions and situations of this study, the following conclusions appear to be justified.

1. The TB group produced significantly more solutions (correct sortings) than the RL group and produced concepts at a significantly higher rate (mean vocalizations per 100 sec.).

2. Solvers produced concepts at a significantly higher rate than nonsolvers.

3. Solutions and concept-evocation rate are positively and highly related.

4. The order and frequency of vocalization of particular concepts are similar for the RL and TB groups.

(Manuscript received February 6, 1951)

References

1. Marks, M. R. Problem solving as a function of the situation. *J. exp. Psychol.*, 1951, **41**, 74–80.

STUDIES IN SHORT-DURATION AUDITORY FATIGUE: I. FREQUENCY DIFFERENCES AS A FUNCTION OF INTENSITY

BY J. DONALD HARRIS, ANITA I. RAWNSLEY, AND PATRICIA KELSEY

U. S. Naval Medical Research Laboratory

This paper presents studies of auditory fatigue using two successive tones of the same frequency. Under these conditions, fatigue refers to the loss in sensitivity to the second tone. Many variables may contribute to this loss, among them being intensity level of the first tone, the duration of either tone, the time elapsing between the tones, or frequency of the tones. Of these variables, frequency is among the more interesting; one wishes to know what portion of the basilar membrane, if any, is most susceptible to fatigue, and to relate this portion to the sound spectra to which the human ear is exposed or may be exposed.

Previous work on the possibility of a differential frequency effect in auditory fatigue is fragmentary and to some extent contradictory. Flügel (**7**) in 1920 investigated the effect of uniaural auditory fatigue upon binaural localization, using forks of 256, 284, 320, and 512 cps. He found no difference from fork to fork, and concluded that (within these limits) fatigue effects are independent of frequency.

The problem is not mentioned in Pattie's 1927 review (**10**) of auditory fatigue. Békésy (**1**) observed in 1929 that as between frequencies of equal physical intensity, no differential effect appeared in the changes of the loudness of tones after the fatiguing stimulus had ceased. However, in a subsequent experiment (**2**) he found that an 800 cps tone produced slightly more fatigue than one of 500 cps when both were at equal sensation level (about 40 db over threshold).

In a preliminary experiment, Rawdon-Smith (**11**) used fatiguing tones of 400, 500, and 2,000 cps, each at 100 db sensation level and of 2-min. duration. Thresholds were taken at these frequencies both before and after the fatiguing stimulus, by the method of limits, using five ascending series in 2-db steps. Since each test tone was 1 sec. in duration, each threshold represents a rough average of the status of the threshold over perhaps a full minute of time (during which the threshold would be expected to change progressively). Furthermore, after each fatiguing tone, *E* took thresholds at each of three frequencies, in random order; so that the exact time (after the fatiguing stimulus) cannot be estimated when a certain threshold was determined. Notwithstanding, a frequency difference appeared. Six of seven *S*s showed no fatigue under these conditions at 400 or 500 cps, while one *S* twice showed fatigue of 15 db at the fatiguing frequency. This is contrasted with the case at 2,000 cps, where at the same frequency all seven *S*s showed fatigue, ranging from 7 to 50 db. No fatigue was exhibited when these experiments were repeated using tones of 80 db sensation level.

In a subsequent paper, Rawdon-Smith (**12**) provided data from which one may make a comparison between fatigue at 400 and 2,000 cps, with constant sensation level (100 db) and duration of stimulation (2 min.). Seven *S*s exhibited fatigue at 400 cps averaging 9.4 db (range 1–18 db), and 12 *S*s exhibited fatigue at 2,000 cps averaging 16.1 db (range 0–50 db). The wide range of individual differences by this method, and the fact that the *S*s did not completely overlap between the 400 cps and the 2,000 cps groups, render the greater fatigue at the higher frequency merely suggestive.

Ewing and Littler (**6**) employed a procedure almost exactly like that of Rawdon-Smith, except that after a fatiguing tone only one tone was tested for threshold. These authors did not make a direct attack on a differential frequency effect, but it is possible from their Table VI to state that almost no fatigue occurs under their testing conditions when a tone of 100 db sensation level and of 2-min. duration is used, whether of 256, 512, 1,024, or 2,048 cps.

Bronstein and Churilova (**3**) used, as an index of fatigue, the time in seconds before the fatigued threshold returned to normal. They found a definite relation between duration of fatigue and frequency, using tones from 100 through 4,000 cps. Each tone was at a 94-phon loudness level, and stimulated the ear for 2 min. On the average for four *S*s (there were marked individual differences) the duration of fatigue ranged from 20

sec. at 100 cps to 280 sec. at 4,000 cps. Unfortunately, no mention was made of the procedure by which thresholds were collected nor of how many seconds this procedure consumed.

Göran de Maré (5) was the first to realize the extreme importance of controlling the time after stimulation before a threshold is taken. Rather than collecting data over a period of 30 sec. or longer, he first collected threshold data on tones A and B, after which he presented tone A for a few seconds; then, following a carefully regulated short interval, he required *S* to indicate whether he heard tone B, lasting .4 sec. This whole cycle was repeated until a threshold intensity could be stated for tone B. When tone A was 2.7 sec. long, the interval of silence 3.1 sec., and tone B was .4 sec., no fatigue could be demonstrated either at 512 or 2,048 cps when the sensation level was as high as 88 db (20 *Ss*). When, however, the interval of silence was shortened to between zero and .7 sec., a definite frequency effect was shown. For any interval of silence used (0, .2, .4, or .7 sec.), more fatigue was shown at 2,048 than at 512 cps, but a measurable effect occurred at 512 cps, in contrast to the findings of earlier studies.

Larsen (8) very briefly reports having fatigued the ear for 5 min. with a pure tone of about 100 db sensation level; 5 min. later a threshold was determined. He states that fatigue varied with frequency, being greatest for tones of 1,024 and 2,048 cps, "whence it decreased to both sides."

Caussé and Chavasse (4) investigated fatigue at 12 frequencies from 100 to 10,000 inclusive. Sensation level was constant at 30 db; each tone lasted 30 sec. Thresholds were determined by the method of limits, using one ascending and one descending series, requiring about 25 sec. A differential frequency effect was seen, though since the fatigued threshold was a rough average from a 25-sec. elapsed time after stimulation ceased, fatigue was of the order of only a few db at most. In a control experiment, Caussé and Chavasse proved the effects to be peripheral rather than central, in contrast to the earlier thinking of Rawdon-Smith, and argued that the latter's conclusion of a central locus arose from his use of a tone of 100 db sensation level, which by cross-conduction affected the other ear.

Lüscher and Zwislocki (9) directly attacked the problem with which this paper is concerned, using a short fatiguing tone (.4 sec.) and a very short test or probe tone (20 msec.). The effect of the first tone on the threshold of the second was measured. Data were presented on one *S* using 7 frequencies from 125 through 8,000 cps, at equal intensity levels from 30 through 80 db with respect to .0002 microbar. Also presented were average data on 16 *Ss* at frequencies from 500 through 8,000 cps, using a single intensity level (80 db). In this work very definite differential frequency effects appeared, which will be discussed later.

The present paper extends the work of Lüscher and Zwislocki in certain respects, and particularly examines the question of how the differential frequency effect depends upon intensity, loudness, and sensation level.

Experimental Design

Auditory fatigue is defined in this paper as the shift in threshold of a pure tone caused by exposure of the ear to a previous pure tone, both tones always of the same frequency. The duration of the first, or fatiguing, tone was 300 msec. The duration of the second, or test, tone was 30 msec. An 80-msec. interval of silence elapsed between the tones. The frequencies studied were 256, 512, 1,024, 2,048, 4,096, 5,747, and 8,192 cps. The intensity of the first tone ranged from 20 through 70 db sensation level. Five or ten determinations of fatigue were made for each frequency at each intensity. Five *Ss* were tested individually.

From the graphs relating fatigue to intensity of the first tone, it is possible to read or to interpolate the amount of fatigue at any physical intensity, any loudness level, or any sensation level within the experimental limits. From these data, then, a picture can be drawn of how fatigue varies with frequency for any one of three intensity parameters.

Apparatus

Two audiometers[1] were used to produce the first and second tones and to regulate their intensities. A Hewlett-Packard direct-reading frequency meter, with accuracy better than 1 per cent, was used to set the frequency. The duration of each tone and the interval between them were controlled by a three-sequence Predetermined Electronic Counter (Potter Instrument Co.) which was located outside the soundproof room and operated by means of a micro-

[1] Western Electric, Model 6B and 6BP.

switch in *E*'s hand. The instrument is accurate to within less than a millisecond.

Headbands were provided for both *S* and *E*. Each headband carried one Permoflux PDR-8 headphone and one wooden replica, both mounted in supra-aural cushions.[2]

Procedure

At the beginning of each experimental session the audiometer producing the first tone was set at the desired frequency after coupling it to the direct-reading meter, and the frequency of the second tone was quickly equated to the first by the technique of aural beats. The *S* at this point put on his headband and adjusted it for comfort. Then, without further adjustment of the headband, three thresholds were obtained in the following order: (a) for the first tone alone, by the serial method of limits (two ascending and two descending series); (b) for the second tone alone, by the method of constant stimuli (five or in some cases ten judgments at intensity levels in 2.5 db steps at random until 100 per cent and zero per cent positive responses occurred); and (c) for the second tone preceded by the first tone, by the method of constant stimuli exactly as for (b). The difference between thresholds (b) and (c) was used as the measure of fatigue.

In determining threshold (c), the fatigued threshold, *S* was first given several sequences of both tones in the temporal pattern described above, with the second tone well above, and then well below, his threshold. This allowed him to stabilize his criterion of whether he heard a second tone. As the experimental sessions continued, this practice was reduced to two sequences per session or whenever *S* called for it. The *S* was required to respond positively or negatively to every sequence except those used for practice. In cases of uncertainty, no data were recorded and the sequence was repeated.

After the fatigued threshold had been determined, *S* was allowed to remove his headband and rest until he again felt prepared to undergo another session, whereupon the audiometers were set to a new frequency and the entire three-threshold procedure was repeated.

Five or in some cases ten determinations of fatigue were made at each frequency for each of a selection of sensation levels from 20 through 70 db.

Finally, for each *S* individually, the mean threshold, its standard deviation and standard error, were calculated for each experimental condition.

[2] Earphone mounting NAF-48490-1, Tyler Rubber Co., Andover, Mass.

Results and Discussion

The pertinent data for the several experimental conditions are shown in Fig. 1. In Fig. 1, for example, at 256 cps, when the first tone was 20 db sensation level, the average *S* showed fatigue of 6.7 db, whereas when the first tone was 70 db sensation level, the average *S* showed fatigue of 44.8 db. Since the distributions of individual threshold determinations were determined to be approximately normal, means have been used here and throughout the paper.

Examination of the standard errors for individual *S*s shows that if one wishes to know the mean fatigue at a certain frequency and intensity, with a precision expressed by a standard error of about ±2 db, it is necessary to make about five determinations; but if one wishes to attain a precision expressed by a standard error of only about ±1 db, it is necessary to make about ten determinations.

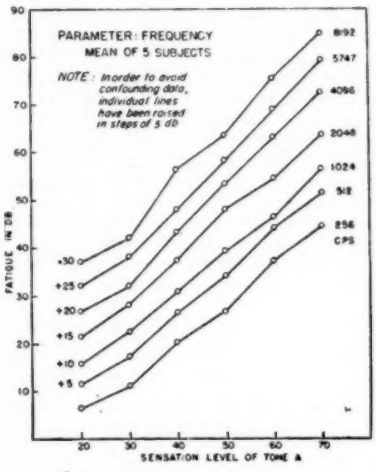

Fig. 1. Fatigue in db as a function of sensation level of Tone A

Individual differences do exist. At 30 db SL, an average of 7.1 db for all frequencies separates the most from the least fatigable *S*. At 70 db SL, this figure is 9.8 db. When, however, one examines the change in fatigue with frequency, for any one of the intensity parameters, it is clear that all five *S*s behaved essentially alike. This point is illustrated for the 50-phon isophonic contour, in Fig. 2. In general, all five *S*s sustain greater fatigue with higher frequencies, in a straight-line fashion at least up to a certain frequency. Thus, an average of the five *S*s would seem to represent the true state of affairs.

In assessing the effect of frequency upon fatigue, a major consideration is the method of equating frequencies in the dimension of intensity. Quite different results are obtained when all the tones are the same intensity above threshold, and when all the tones are equally loud. Still a different result obtains if all tones are of equal physical intensity.

One step in assessing the fatiguing effect of various frequencies is to make them all of the same physical intensity. When this is done, a family of curves results as in Fig. 3. Here, fatigue is plotted against frequency, with intensity as the parameter. In this figure, fatigue refers to the difference between the momentary threshold and .0002 microbar. A general similarity is seen between fatigue data and the equal-loudness contours of Fletcher and Munson. This similarity was emphasized by Lüscher and Zwislocki from data on one *S* (**9**). If the data of Fig. 3 were closely similar to equal-loudness contours, then one would reason that at intensities of about 80 db and above (where equal-loudness contours are approximately straight lines) fatigue is a function of intensity and is independent of frequency. The data of Fig. 3 do not, however, support this conclusion unequivocally. At all intensities used here, a frequency effect appears.

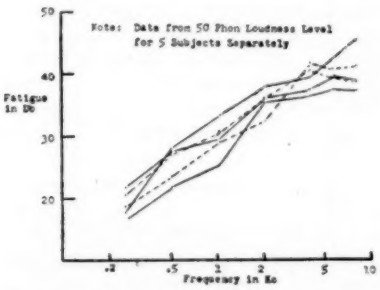

FIG. 2. Fatigue in db as a function of tonal frequency at the 50-phon loudness level (5 *S*s)

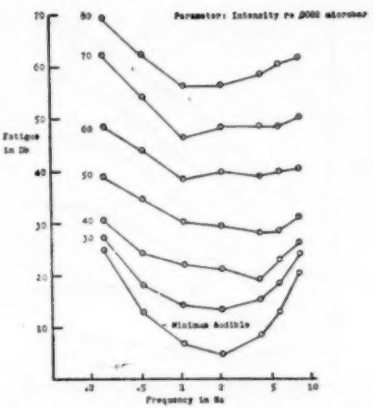

FIG. 3. Fatigue, as measured by the difference between the momentary threshold and .0002 microbar, as a function of tonal frequency and intensity (mean for 5 *S*s)

But the equating of different frequencies should perhaps take into account not only the physical intensity, but also the phenomenon of loudness. Figure 4 shows fatigue plotted against frequency, with loudness-level as the parameter. At the 30-phon level a definite tendency begins for the

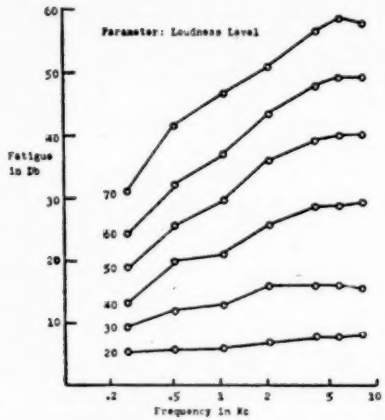

FIG. 4. Fatigue in db as a function of tonal frequency and loudness level (mean for 5 Ss)

higher frequency regions to undergo more fatigue, a tendency which increases with loudness level until at 70 phons a difference of more than 27 db exists between the fatigue at 256 and 8,192 cps. Since this difference obtains when the two frequencies are equally loud, then evidently (at about 30 phons and louder) the loudness of a tone is not the prime determiner of its fatiguing effect.

It is very significant that the fatiguing effect of a tone does not in many cases depend directly on its loudness. If one makes the common assumption that loudness is some function of nerve impulses per unit time, it is hard to see how the fatigue of this experiment could have its site in the nervous system. A more likely site would be the peripheral receptor itself, for which many differential frequency effects are already well established.

There remains a third method of equating different frequencies, namely, rendering them all of equal intensity each above its minimum threshold (i.e., equal sensation level). This notation has the advantage that for each individual *S* it can be much more quickly determined than the phon; furthermore, it takes into account the threshold audiogram, which the physical intensity does not. Thus, although it actually has only a derived significance in the realm of sensation, nevertheless sensation level in db is an often-used approximation to the loudness of a tone, and is indeed used on all audiometers. Figure 5 shows fatigue plotted against frequency, with sensation level as parameter. It is clear that through the levels from 20 through 40 db, fatigue can be predicted from sensation level without regard to frequency; but above 40 db, the higher frequencies occasion greater fatigue. The differential frequency effect at the highest level, 70 db, is, however, only 10 db between 256 and 8,192 cps (as compared with the 27-db difference cited above for the 70-phon level).

The question of whether a differential frequency effect exists in the field of auditory fatigue may now be examined from three points of view, depending on whether one equates

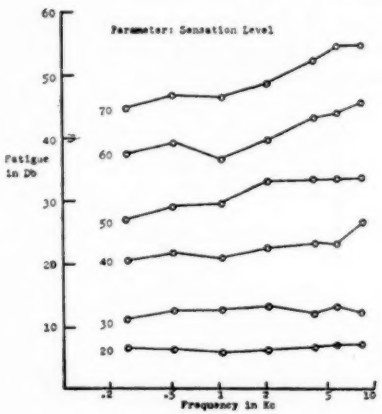

FIG. 5. Fatigue in db as a function of frequency and sensation level (mean for 5 Ss)

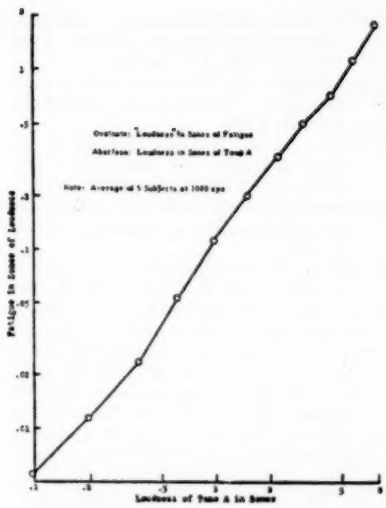

FIG. 6. Fatigue in sones of loudness as a function of loudness of Tone A in sones (mean of 5 *Ss* at 1,024 cps)

frequencies as to intensity, sensation level, or loudness. At generally weak intensities, it is preponderantly sensation level which determines fatigue, while at stronger intensities there is a trend for physical intensity to determine fatigue. If one equates the most direct psychological correlate of intensity, namely, loudness, it is clear that a strong differential frequency effect exists at almost all intensity levels, the higher frequency regions being much more susceptible of momentary loss.

It may be of interest to observe how fatigue increases with increasing intensity, when both intensity and fatigue are expressed not in db, as in Fig. 1, but rather in the true unit of loudness, the millisone. Figure 6 shows the average data for 1,024 cps. This curve is especially instructive when compared with those in Fig. 1. From those curves it is seen that (from sensation levels of about 30 db and up) a 10-db increment in the fatiguing tone occasions about a 10-db increment in fatigue. If this were exactly true, of course, all curves in Fig. 1 would be 45° diagonals. There are exceptions to this, though most of the divergences are within experimental error; in any case the slope of the curve in Fig. 6 is distinctly *not* a 45° diagonal, but shows that a certain increment in millisones of Tone A causes a proportionately greater fatigue.

SUMMARY AND CONCLUSIONS

The method of short-duration auditory fatigue allows for rapid accumulation of data since all effects of stimulation with brief tones disappear in usually less than a second. In this experiment, Tone A of 300 msec. was followed after 80 msec. by Tone B of 30 msec. Both A and B were the same frequency, either 256, 512, 1,024, 2,048, 4,096, 5,747, or 8,192 cps. Tone A was set at intensities ranging from 20 through 70 db sensation level. Fatigue was calculated as the difference in threshold of Tone B preceded and not preceded by Tone A.

A comparison of fatigue among frequencies was made when they were equated as to intensity, loudness, and sensation level. Equating as to intensity led to curves which bear similarities to isophonic contours, and lends some support to Lüscher and Zwislocki's view that the frequency characteristic depends upon intensity rather than loudness.

A family of fatigue curves equated for loudness shows that, especially at equal-loudness levels of 40 phons and above, fatigue is a decided function of frequency. At the 70-phon level, a tone of 8,192 cps suffers 27 db more fatigue than a tone of 256 cps. This differential effect is considerably less

evident when frequencies are of equal sensation level.

(Manuscript received February 16, 1951)

References

1. Békésy, G. v. Zur Theorie des Hörens: Über die Bestimmung des einem reinen Tonempfinden entsprechenden Erregungsgebietes der Basilarmembran vermittels Ermudungsercheinungen. *Physik. Ztschr.*, 1929, **30**, 115–125.
2. Békésy, G. v. Zur Theorie des Hörens: Über die eben merkbare Amplituden-und Frequenzanderung eines Tones. Die Theorie der Schwebungen. *Physik. Ztschr.*, 1929, **30**, 721–745.
3. Bronstein, A. S., and Churilova, E. A. The dependence of time taken to restore the initial excitability of the hearing apparatus upon the pitch of the acting tone. *Bull. Biol. Méd. exp.*, 1936, **1**, 428–430.
4. Caussé, R., and Chavasse, P. Nouvelles recherches sur la fatigue auditive. *C. R. Soc. Biol.*, 1945, **139**, 465–467.
5. de Maré, G. Audiometrische Untersuchungen. *Acta oto-laryng. Supplement*, 1939, **31**, 1–173.
6. Ewing, A. W. A., and Littler, T. S. Auditory fatigue and adaptation. *Brit. J. Psychol.*, 1934, **25**, 284–307.
7. Flügel, J. C. On local fatigue in the auditory system. *Brit. J. Psychol.*, 1920, **11**, 105–134.
8. Larsen, B. Investigations in the fatigue of hearing. *Acta oto-laryng.*, 1942, **30**, 525.
9. Lüscher, E., and Zwislocki, J. The decay of sensation and the remainder of adaptation after short pure-tone impulses on the ear. *Acta oto-laryng.*, 1947, **35**, 428–445.
10. Pattie, F. A. An experimental study of fatigue in the auditory mechanism. *Amer. J. Psychol.*, 1927, **38**, 39–58.
11. Rawdon-Smith, A. F. Auditory fatigue. *Brit. J. Psychol.*, 1934, **25**, 77–85.
12. Rawdon-Smith, A. F. Experimental deafness. *Brit. J. Psychol.*, 1936, **26**, 233–244.

OPERANT EXTINCTION AS A FUNCTION OF THE EXTINCTION SCHEDULE

BY DONALD H. BULLOCK

University of Buffalo[1]

Among the factors influencing reflex strength during extinction are those variables involved in the extinction schedule, sometimes referred to as "massed" and "spaced" extinction. A number of studies have dealt with the extinction of conditioned operants as a function of the extinction schedule (**1, 3, 6, 7, 8, 9, 10**). Sheffield (**10**) and Rohrer (**9**) have both presented adequate historical accounts of the problem. Concerning the present status of the extinction schedule as a variable, Sheffield (**10**) states: "Thus it may be seen that the evidence is rather tenuous for the commonly-accepted conclusion that extinction is faster if extinction trials are massed than if spaced."[2]

In dealing with the effect of the extinction schedule upon operant extinction, a number of factors must be considered:

1. As the intertrial or interextinction interval (henceforth: the time-out interval) is increased, the amount of deprivation time is proportionally increased. As the extinctions cumulate, the drive strength differential between groups with longer and shorter time-out intervals increases. With the exception of Sheffield, previous investigators have failed to concern themselves with this variable. To the extent that they were presumably concerned, however, with one or more assumptions that some sort of extinction-generated "inhibition" was influenced by increased time-out intervals, failure to account for drive differentials prevents any unequivocal conclusions. In Rohrer's (**9**) study, 10- and 90-sec. time-out intervals were used, so that with each extinction trial a cumulative 80-sec. difference in deprivation was produced. In one pair of groups, the 10-sec. time-out interval *Ss* required a median of 32.5 extinction trials. At the end of this number of trials, this group had been deprived of food on the average 43 min. less than the 90-sec. time-out interval group. Such a discrepancy may or may not represent a significant drive differential. In Ellson's (**1**) study, the time-out intervals ranged from 5.5 to 185 min., a difference of 3 hr. in deprivation between the shortest and longest time-out interval group. This 3-hr. drive differential was cumulated with successive extinctions. Sheffield utilized a control over this drive factor, starting her 15-min. time-out interval group with 16.5 hr. of deprivation, her 15-sec. group with 23 hr. of deprivation, so that at the completion of the extinction schedules the number of hours of deprivation for both groups was approximately equal. In this respect her experiment commands greater unequivocality of result by controlling this important aspect of spacing of extinctions.

2. In dealing with operants, *E* may or may not specifically establish a particular discriminative stimulus control over the operant. In the studies of Sheffield (**10**), Rohrer (**9**), Porter (**6, 7**), and Gagnĕ (**3**), the onset of the situation was controlled by *E*. These initiating circumstances, such as the opening of the door of the starting box, served as discriminative stimuli consistently correlated experimentally with the reinforced behavior. Where such a discriminated operant is utilized, latency measures of one sort or another, rather than response frequency, are used. Latency of a discriminated operant is presumably correlated in a fairly direct manner

[1] This report is part of a dissertation submitted to the Faculties of Pure Science of Columbia University in partial fulfillment of the requirements for the degree of Doctor of Philosophy. The author is indebted to Professors F. S. Keller and W. N. Schoenfeld for their invaluable assistance.

[2] Two terms, "resistance to extinction" and "rate of extinction," have appeared in the literature. Both terms refer to the same things: the number of responses or trials or the amount of time required to reach some extinction criterion. By definition the rate of and resistance to extinction are inversely related: the greater the resistance, the slower the rate; vice versa. The reader should note, where relevant, that this report deals with (a) resistance to extinction, or reserve—the total number of responses obtained in a constant period of time; and (b) rates of response during extinction. These two dependent variables are not necessarily definitionally correlated in any consistent manner.

with the size of the reserve (the strength of the habit). If, however, during extinction, one wants to "drain the reserve," it would seem that a special procedure would have to be used: (a) the preconditioning operant level latency would have to be determined on a series of trials; (b) during extinction this level would be the extinction criterion. Such a procedure has not, as far as is known, been used to date. This makes it impossible to state in such situations—where a specific discriminated operant and latency measures are used—whether or not the extinction schedule influences the reserve. Skinner's (11) formulation of the concepts of reserve and immediate reserve is such that variation in the extinction schedule should not affect the over-all reserve with regard to nondiscriminated operants. The data presented in this paper suggests that his formulation is correct.

3. The extinction schedule could conceivably influence extinction in two ways: (a) increase the *initial* rate of response without affecting the total reserve; (b) increase both the initial rate and the total reserve. To determine which of these two possibilities occurs, it is necessary to allow for adequate drainage of the reserve. Use of a 5-min. criterion of extinction evidently does not allow for adequate tapping of the reserve. Jenkins, McFann, and Clayton (4) have reported that the number of responses emitted to a criterion of 5 min. of no-response does not correlate significantly with the total reserve obtained in 6 hr. This fact, combined with the possible role of drive differentials discussed above, suggests that Ellson's (1) data concerning increased time-out intervals between extinctions were incomplete. His finding was that with increased duration of time-out intervals, resistance to extinction—as measured by number of extinction responses—increased.

The following experiment reports upon variation of extinction schedule in which adequate time for relatively complete drainage of the reserve was provided. The influence of four different durations of time-out intervals —1, 2, 4, and 8 min.—could thus be analyzed with respect to (a) response rate during various stages of the extinction; and (b) the final obtained reserve.

Method

The apparatus consisted of Columbia Skinner boxes, living-experimental cages, removable levers, manually controlled feeders, and polygraphic recorders. The specific units have been described in detail elsewhere (2). Eight such combinations were set up on two tables arranged in an L. In this manner eight *S*s could be experimented upon simultaneously. This allowed for inter-*S* facilitation, since the recorders produced sounds within the experimental room. There was no evidence to suggest, however, that the resulting interaction in any way significantly influenced the results of the experiment.

The procedure consisted of the following steps: (a) Habituation and establishment of a feeding schedule were accomplished at least three days before the first operant level session. (b) Measurement of the operant level of the lever-pressing response was made during five consecutive daily 30-min. sessions during which the lever was available but no reinforcements were experimentally administered. (c) Measurement of the operant level was made during four consecutive daily sessions in which the lever was present or absent according to the schedule to be used during extinction. Prior to this the *S*s were placed in subgroups of four each, the groups being equated in terms of the median number of responses during the final three operant level sessions in (b) above. (d) Conditioning was established by means of continuous reinforcement with finely ground laboratory chow, each reinforcement (except the first and last of each conditioning session, which consisted of ½ gm. each) consisted of approximately 1/20 gm. of food. Thirty reinforcements were administered the first day, 50 the next. (e) Extinction was accomplished according to a prearranged schedule (see below) conducted the day after the second conditioning session, the lever being available a total of 5 hr. for each *S*.

In the original study, the duration of time-in periods was also varied. However, that factor is not relevant to the present article, and as a variable it is confounded in the treatment of results.

Four time-out intervals were used, 1, 2, 4, and 8 minutes. The first part of the extinction consisted of a series of time-in—time-out cycles, the lever being present a total of 32 min. The time-in period remained the same for a given *S*, as did the time-out interval. The number of cycles varied as a function of the duration of the time-in periods. This variable is confounded in the treatment of the results. Following the last time-out interval, the lever was then continuously available for 4½ hr. For each *S*, then, there were 32 min. of systematically interrupted extinction and 4½ hr. of noninterrupted extinction, a total of 5 hr. of lever availability.

Drive was not adequately controlled, as will be discussed in Results. The research was completed before it was realized that drive variation occurred concomitantly with time-out interval

duration. The *S*s had been deprived of food for approximately 20 hr. prior to each experimental session.

The *S*s were 64 male albinos of the Wistar strain, 90–110 days of age at the start of experimentation. Two were discarded because of experimental error.

Results

Table I presents the median cumulated response extinction curves for the 1-, 2-, 4-, and 8-min. time-out interval groups at selected points during the total 5 hr. of extinction. At the end of the 32 min. of interrupted extinction there is a significant deviation of the four medians from a chance expectancy, as determined by chi-square.[3] With the exception of the 2-min. time-out group, there is a general trend for the longer time-out intervals to have generated a greater rate of response during the first 32 min. of extinction. During the remaining 4½ hr. of extinction, however, there is a compensatory reversal in rate of such a nature that after a total of 5 hr. there is no significant deviation in the median total number of extinction responses cumulated by each group. Figure 1 shows the cumulated curves for the 1-min. group and the combined 2-, 4-, and 8-min. groups, as well as the difference between the cumulated curves at selected points. The difference at the end of 32 min. between the 1-min. and the combined 2-, 4-, and 8-min. groups was 37.5 responses (based on the median cumulated response curves). The t was 1.80, df 60, level of confidence .085. At the end of 5 hr. the difference was .5 responses. This figure shows strikingly the apparent effect of increased time-out interval duration: (a) There is an initial increase in response rate. Comparison of these groups during both the noninterrupted and interrupted operant level sessions showed no significant differences. The effect shown in Table I and Fig. 1 represents a post-conditioning phenomenon. (b) There is a compensatory reversal in response rate, so that the final reserves are not significantly influenced. These data are not comparable to those of Sheffield, Rohrer, Porter, and Gagné, who used specifically discriminated operants. However, with respect to Ellson's (1) data, these findings are contradictory. He reported an apparently increased reserve with longer time-out intervals. Three factors are important here: Ellson used longer intervals, ranging from 5.5 to 185 min.; the cumulated drive discrepancies of Ellson's groups were much greater than those of the present

TABLE I

Median Cumulative Responses during Extinction in Groups Having 1-, 2-, 4-, and 8-Min. Time-Out Intervals during 5-Hr. of Interrupted and Noninterrupted Extinction

Time in Min.	Time-Out Group				χ^2	p
	1 Min.	2 Min.	4 Min.	8 Min.		
10	58.5	83.0	59.0	83.5	8.7	.04
20	83.5	109.0	87.5	125.0	11.2	.01
32*	96.5	135.0	120.0	139.0	9.3	.03
40	109.0	158.5	131.5	149.5	10.5	.02
50	109.0	160.5	132.5	151.0	11.2	.01
60	109.0	160.5	141.5	151.0	10.6	.01
90	115.0	161.5	144.0	158.5	9.3	.04
120	120.0	170.0	144.0	160.0	10.1	.03
150	127.0	174.5	157.0	163.0	7.9	.05
180	141.0	176.5	165.0	163.5	4.1	.25
210	150.5	190.0	171.5	163.5	3.4	.34
240	158.0	194.5	179.5	166.0	4.4	.23
270	166.5	195.0	181.5	168.5	2.9	.40
300	176.0	196.5	185.0	179.0	1.3	.70

* Point at which interrupted extinction session terminated.

[3] Chi-square was obtained by assuming "e" to be the median of the four median cumulated response curves at any particular point during extinction at which the test was to be applied. For example, if the median curves for the four groups at one hour were 98, 102, 110, and 118, then "e" was assumed to be 106. "O" would then be the actual median curves at this point, e.g., 98, 102, 110, and 118.

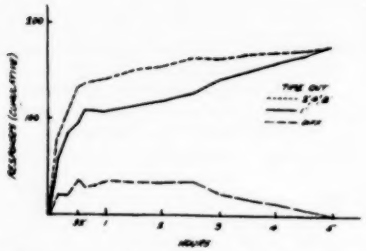

FIG. 1. Median cumulative response extinction curves for the 1-min. and the combined 2-, 4-, and 8-min. time-out groups, and the difference between them at selected points during the 5-hr. extinction period.

groups (Skinner [12] has reported data showing that increased drive during extinction increases reserve); and Ellson used a 5-min. extinction criterion, which, as suggested earlier, may prevent adequate drainage of the reserve, thus disclosing only the initial increase in rate but not the compensatory reversal which brought about, in the present data, no equalization of the final median reserves of the four groups. The first two factors can be deduced from Skinner's formulation of the concepts of reserve and immediate reserve. With longer time-out intervals, there is greater accumulation of the responses in the immediate reserve from the total reserve. When

TABLE II

MEAN TOTAL TIME OF FOOD DEPRIVATION AT THE END OF 32 MIN. AND 5 HR. OF EXTINCTION FOR THE FOUR TIME-OUT INTERVAL GROUPS

Time-Out Interval in Min.	After 32 Min. of Extinction	At the End of 5 Hr. of Extinction
1	20 hr. 45 min.	25 hr. 15 min.
2	21 hr. 0 min.	25 hr. 30 min.
4	21 hr. 30 min.	26 hr. 0 min.
8	22 hr. 30 min.	27 hr. 0 min.

the lever is made available, more responses are immediately available. Response rate is facilitated. The total reserve, however, is not affected, merely drained more rapidly. Eventually the heightened rate of drainage of the total reserve produced by the longer time-out intervals must be followed by the observed reversal in rate.

Figure 2 presents the relationship between the time-out interval duration and the median rate of response per minute during the first 32 min. of interrupted extinction, as determined by obtaining the median for the specific time-out groups from the responses per minute for three pe-

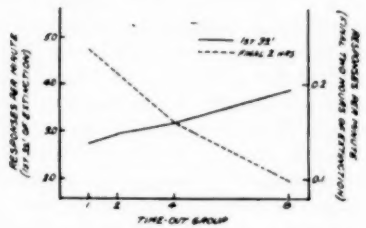

FIG. 2. The relationship between the time-out interval and (1) the median rate of response per minute during the first 32 min. of extinction (interrupted), and (2) the median rate of response per minute during the final 2 hr. of extinction (noninterrupted)

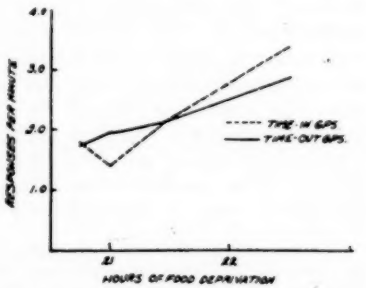

FIG. 3. The relationship between the mean number of hours of food deprivation at the end of the first 32 min. of extinction (interrupted) and the median rate of response per minute during that interrupted extinction for the time-out and time-in groups

riods: (a) the first 10 min.; (b) the second 10 min.; and (c) the final 12 min. Figure 2 also shows the median rate of response per minute during the final 2 hr. of noninterrupted extinction, as determined by taking the number of responses emitted during this period by a specific *S* and dividing by 120 (minutes). This last is a rather gross indicator, but nevertheless, the comparison of the initial and final response rates is of some interest.

As was mentioned earlier, drive differentials represent a complicating variable. Table II shows the differences in the mean number of hours of food deprivation for the time-out groups at the end of the 32 min. of interrupted extinction. Figure 3 shows the relationship between these deprivation durations and the median rate of response per minute during the 32 min. of interrupted extinction for the time-out groups. The data show that the effect of the time-out intervals upon response rate might be accounted for on the basis of drive discrepancies.

Data from Perin (5) on the relation between the hours of food deprivation and the resistance to extinction of the lever-pressing response are available, enabling an *estimate* of the effect of the drive discrepancies shown in Table II. With regard to the number of responses emitted to a criterion of 5 min. of no-response, Perin's theoretical curve predicts a 10–12.5 per cent difference between the two time-out groups in the present experiment with the greatest difference in hours of deprivation. The actual difference obtained between these groups was 44 per cent. With regard to the effect of drive differences upon the rate of response during the first stages of extinction, Perin's data showed a difference of approximately .14 responses per minute between his 16- and 23-hr. food deprivation groups. The difference in response rates between the two time-out groups in the present experiment with the greatest drive discrepancy was .95 responses per minute, with a discrepancy of 105 min., as compared with Perin's 7-hr. difference. This difference in responses per minute in the present data is seven times as large as the greatest possible difference estimated from Perin's data.

The above comparison with Perin's data indicates that the obtained increased initial response rate with longer time-out intervals is appreciably greater than would be expected on the basis of drive differences alone. Obviously, drive factors may have played some role. But the greater part of the rate facilitation seems to require explanation in terms of some interextinction interval factor other than drive (such as cumulation of responses in the immediate reserve).

Summary

An experiment has been reported dealing with the relationship between the duration of time intervals separating extinction periods during the extinction of an operant (lever-pressing) conditioned by means of continuous reinforcement with food and the response rate during extinction and the total number of extinction responses.

1. The longer the time-out interval, the greater the tendency for facilitation of response rate during the interrupted extinction (32 min.).

2. Variation in duration of the time-out interval did not significantly influence the over-all reserve, i.e., the total number of extinction responses emitted in 5 hr. of interrupted and noninterrupted extinction.

(Manuscript received March 6, 1951)

References

1. Ellson, D. G. Successive extinctions of a bar-pressing response in rats. *J. gen. Psychol.*, 1940, **23**, 283–288.
2. Frick, F. C., Schoenfeld, W. N., and Keller, F. S. Apparatus designed for introductory psychology at Columbia College. *Amer. J. Psychol.*, 1948, **61**, 409–413.
3. Gagné, R. M. The effect of spacing of trials on the acquisition and extinction of an operant response. *J. exp. Psychol.*, 1941, **29**, 201–216.
4. Jenkins, W. O., McFann, H., and Clayton, F. L. A methodological study of extinction following aperiodic and continuous reinforcement. *J. comp. physiol. Psychol.*, 1952, **45**, (in press).
5. Perin, C. T. Behavior potential as a joint function of the amount of training and

the degree of hunger at the time of extinction. *J. exp. Psychol.*, 1942, **30**, 93–113.

6. Porter, J. M., Jr. Extinction of an acquired response as a function of the interval between successive non-reinforced elicitations. *J. comp. Psychol.*, 1938, **26**, 261–270.
7. Porter, J. M., Jr. Experimental extinction as a function of the interval between successive non-reinforced elicitations. *J. gen. Psychol.*, 1939, **20**, 109–134.
8. Reynolds, B. Extinction of trace conditioned responses as a function of the interval between successive non-reinforced elicitations. *J. gen. Psychol.*, 1945, **35**, 81–95.
9. Rohrer, J. H. Experimental extinction as a function of the distribution of extinction trials and response strength. *J. exp. Psychol.*, 1947, **37**, 473–493.
10. Sheffield, V. Resistance to extinction as a function of the distribution of extinction trials. *J. exp. Psychol.*, 1950, **40**, 305–313.
11. Skinner, B. F. *The behavior of organisms.* New York: Appleton-Century, 1938.
12. Skinner, B. F. Personal communication reported in F. S. Keller and W. N. Schoenfeld, *Principles of psychology.* New York: Appleton-Century-Crofts, 1950.

THE EFFECT ON EXTINCTION RESPONDING OF STIMULI CONTINUOUSLY PRESENT DURING CONDITIONING[1]

BY CHARLES B. FERSTER[2]

Columbia University

The environmental control of operant behavior may be classified under three stimulus-response-reinforcement relations. The first case is the usual discrimination procedure: Two aspects of the environment are arbitrarily chosen and in the presence of one stimulus a given response is regularly reinforced. When the other stimulus is presented, the responding that occurs through generalization will go unreinforced. By establishing such a stimulus-response-reinforcement relation, it is possible to achieve a high degree of control over the emission of the response. At a given drive level, a response will occur with a short latency when the discriminative stimulus (S^D) is present and in the presence of the nonreinforced stimulus (S^Δ) a near zero rate of response is achieved (10, p. 186). Subsequent extinction of the response will be incomplete unless the S^D is present (3).

A second kind of stimulus-response-reinforcement relation involves periodic reinforcement in the presence of S^D, together with nonreinforcement in the presence of a second stimulus, S^Δ. In this case, the response does not *always* produce a reinforcement when the discriminative stimulus is present. As in the first case mentioned, however, the response goes unreinforced when the second stimulus (S^Δ) is present. A marked difference in the rate of response under the two stimuli results[3] and subsequent extinction is incomplete unless the discriminative stimulus is present (4). It will be noted that in both of the preceding cases there is differential reinforcement with respect to the two stimuli. In a manner of speaking, the organism is forced to pay attention to the stimulus differences.

A third case remains, in which there is no differential reinforcement of the response. Such a case might involve the *continuous* presence of the stimulus during continuous, periodic, or aperiodic reinforcement. Questions arise concerning the manner in which such an accompanying stimulus may exert control over a response. Specifically, the present investigation is concerned with whether the stimulus, present continuously during conditioning, exercises any control over the number of responses in subsequent extinction. The literature contains three pertinent studies.

Skinner (10, p. 180) gave eight rats 50 regular reinforcements for lever pressing during a period of continuous light. On the following day, extinction was begun in the dark. The light was reintroduced after 40 min. in the case of four of the rats and after 20 min. in the case of four others. In every instance the rate of response increased when the light was introduced, although the effect was small. Skinner states: "It was not clear . . . whether the effect of the light was to produce a second extinction curve . . . or whether an increase in rate occurred for which there is later compensation" (10, p. 182). In other experiments (concerned with the problem of disinhibition, but serving conveniently as controls for this experiment) stimuli without conditioning histories were introduced during extinction. It was found that in many

[1] This paper is an abridgment of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Faculty of Pure Science, Columbia University, New York, 1950.

[2] Now at Harvard University

[3] From an unpublished study by B. F. Skinner.

instances these stimuli also served to increase the rate of response. "It was obvious in all these cases, however, that the stimulus was administered at a time when the record was below its envelope, and that the extra responses only brought it up to its proper position" (10, p. 100).[4] Skinner raises the question of how the effect of the novel stimulus differs from the effect of a stimulus present continuously during conditioning.

Winnick (11) repeated Skinner's experiment, using periodic reinforcement at fixed interval. She conditioned a group of rats with a light continuously present and found that in each of five rats the rate of response, after a period of extinction in the dark, increased when the light was introduced. The light employed, however, was clearly aversive since another group of rats in her study was conditioned through its removal. An increase in rate such as was obtained by Winnick may be, at least in part, ascribed to the emotional effect of the light.

Cook (2) used a procedure which was essentially the same as that employed by Winnick and Skinner and obtained a similar result. The stimulus he employed was an unshielded 60-w. lamp. The removal of such an intensity has been successfully used to condition an escape response and therefore probably had aversive properties. Yet the effect obtained by Cook was of considerable magnitude and it is doubtful whether the aversive character of the stimulus alone could account for the result.

Another basis for the findings of these investigators lies in other behaviors of the rat in the bar-pressing situation. Although lever pressing is the only aspect of the rat's behavior that is customarily recorded, it must be recognized that it is but one of the several responses involved in the bar-pressing chain. Approach to the lever is an operant whose discriminative stimuli include visual, tactual, and proprioceptive components. Not all of the locomotion of the rat brings him into a position where pressing the lever is possible. If, for example, the rat happens to be facing the rear of the cage and moves in that direction, then the same locomotor response involved in approaching the lever will have been made in the absence of any stimulation from the lever itself. Because of the nonreinforced approach responses to parts of the cage other than the front, the visual lever and other visual aspects of the cage come to function as discriminative stimuli for approach to the lever and for rising up to the lever. If training is carried out in an illumination of sufficient intensity to permit the utilization of such S^D's and extinction is then begun in the dark, this extinction will be incomplete. Some of the stimulus components for lever approach, however, will be restored when the light is reintroduced, and a number of responses under the control of the visual S^D's will occur.

[4] It may be noted, in view of discussion to come, that in each instance where the novel stimulus was a light, a rise was observed in the rate of response.

Method

In the present experiment, a light of low intensity was selected, in an attempt to eliminate both the aversive properties of the stimulus and the possible use of stimulation by objects in the cage. While the rat could readily discriminate between darkness and the intensity of light employed, the level of illumination was so low (.01 ft.-candles) that visual acuity should have been seriously impaired. A tone which was simultaneously present with the light could not, of course, disclose variable stimuli that might exercise a discriminative influence.

Subjects.—The *S*s of the experiment were 68 male albino rats of Wistar stock, approximately 100 days old on arrival at the laboratory and 130 days old at the start of the experiment.

Apparatus.—The *S*s were housed in cages which served both as living quarters and experimental chambers. A more detailed description of the cages is given by Frick, Schoenfeld, and Keller (5). A slot at one end permitted the insertion of a lever, and a tube passing beneath the slot provided for the delivery of food pellets to a small tray within the cage.

The experimental room was kept darkened and *E* remained outside the room while the experiment was in progress. Room temperature was thermostatically controlled and varied between 75° and 80° F. Control and recording apparatus was kept in an adjoining room and could not be heard inside the experimental chamber.

A combination of stimuli was employed, consisting of a continuous tone and an intermittent light. The tone was generated by a code oscillator having a fundamental frequency of 750 cy./sec. An oscillograph record of the tone, however, revealed that it had other frequencies at various intensities. The intermittent light had a 2-sec. cycle, 1 sec. on and 1 sec. off, and raised the illumination inside the cage to .01 ft.-candle. When the light was not present, the illumination inside the cage was too low to be measured by a Macbeth illuminometer.

The apparatus permitted three rats to be run simultaneously. However, since the cages were not sound insulated from each other, it was necessary to give each group of three the same experimental treatment.

Procedure.—Drive was maintained by a 23-hr. feeding schedule. For five days prior to the beginning of experimentation, *S*s were fed during the hour following the period in which they were to be run. Water was available at all times.

The conditioning procedure was the same for all *S*s. Throughout training, the light and tone were present continuously whenever the levers were in the cage. At the beginning of the first experimental period, 15 pellets were deposited in the food tray, with the light and tone present. When *S* had eaten the pellets, the lever was inserted into the cage and each lever press caused the delivery of a pellet. When 95 to 100 reinforcements had been received, the levers were withdrawn from the cage and *S* was removed from the experimental room. Conditioning was immediate in almost every case, but one *S* had to be discarded because he failed to condition within the hour.

On the second day, an aperiodic schedule of reinforcement was introduced. Bar-pressing was effective in producing a food pellet every 2 min. on the average, with a range of 35 to 240 sec. in an arithmetic series. This schedule was carried out for 50 min. on each of three successive days.

For extinction, the rats were divided by lot into four groups. The schedule of stimulus presentation during the three successive 50-min. periods is presented in Table I.

For Group I, the light and tone were present throughout all three extinction periods. For Group II, light and tone were absent throughout all extinction periods. A comparison of these two groups should reveal the degree of stimulus control over the number of extinction responses.

For Group III, extinction was begun in the absence of the light and tone. After 26 min. of the first extinction period had elapsed, the stimuli were introduced, and the remaining extinction periods were carried out in the presence of these stimuli. For Group IV, extinction was begun in the absence of the light and tone. After 26 min. of the second extinction period had elapsed, the light and tone were introduced. An examination of the rates of response following the introduction of the stimuli at these two points should make it possible to test the immediate effect of the stimulus under two markedly different rates of response.

Control studies.—In order to make certain that any results obtained in the experiment were not contaminated by depressive or aversive properties of the stimuli employed, two control experiments were carried out.

In the first control experiment, 36 naive rats (later used in the experiment proper by distributing them among the four experimental groups), 23 hr. hungry, were divided randomly into two groups. Unconditioned rates of bar-pressing were then recorded in the presence of the light and tone for one group and in the absence of the light and tone for a second group. The mean number of responses for the group run in the light and tone was 36.2 in contrast with 33.7 for the group run in the absence of these stimuli. The $\sigma_{diff.}$ between these means was 8.7 and it may be concluded that the operant levels did not differ significantly. Although Keller has shown that the presence of an aversive stimulus can markedly depress operant level rates, the stimuli employed in the present experiment were apparently of too low intensity to exercise such an influence.[5]

In the second control experiment, two naive rats, 23 hr. hungry, were given an opportunity to turn off the light and tone for 30 sec. by pressing the lever, or to keep off the light and tone by holding the lever down. Two-hour records were taken and the rate of response was observed to decline throughout the period, falling almost to zero during the final minutes. There was no indication that the termination of the light and tone served as a reinforcement. On the basis of these two controls, therefore, it is reasonable to assume that the stimuli used had no aversive properties.

Finally, to determine whether the light was supraliminal, discrimination training was given to one rat by presenting the light every 3 min., reinforcing the first response in the light and then turning it off. During 2 hr. of training the rate of response in the dark fell off regularly until it reached a value of less than half of the rate observed at the start of the discrimination procedure. To insure that the drop in rate was due

TABLE I

SCHEDULE OF STIMULUS PRESENTATIONS DURING THREE CONSECUTIVE 50-MIN. EXTINCTION PERIODS

L & T refers to a combination stimulus of Light and Tone. All conditioning is in the presence of light and tone.

Group	Extinction Period					
	1		2		3	
	1–26	27–50	1–26	27–50	1–26	27–50
I	L & T	L & T	L & T	L & T	L & T	L & T
II	None	None	None	None	None	None
III	None	L & T	L & T	L & T	L & T	L & T
IV	None	None	None	L & T	L & T	L & T

[5] Personal communication.

to the formation of a discrimination rather than to lowered drive resulting from the ingestion of food, the stimulus conditions were then reversed, the light becoming S^{Δ} and the darkness becoming S^{D}. The rate of response in the light returned to the value established at the start of training and the discrimination began to form anew. There was no question but that the tone used in this experiment was supraliminal.

Results [6]

A summary of the conditioning and extinction data is presented in Table II. The number of responses made during the last two sessions of aperiodic reinforcement is not of primary interest but the correlation between this total and the number of responses in extinction permits the application of analysis of covariance to the data. Such an analysis was applied to the total number of extinction responses made during each of the three extinction periods. This analysis reveals an F-ratio of less than one, and it may be concluded that there is no reason to believe that the various experimental treatments resulted in differing numbers of extinction responses.

The immediate effect of the stimulus on rate during extinction is examined in Tables III and IV. These data are analyzed in terms of the first 2, 4, and 6 min. following the introduction of the light and tone in Groups III and IV, and the comparable periods in Groups I and II where the light and tone were present and absent, respectively, throughout the entire period of extinction.

Analysis of covariance was applied to these data. The adjusted variances were obtained from a multiple regression equation depending upon the extinction ratio during training and the total number of responses in the extinction period under examination. A separate analysis was carried out for 2, 4, and 6 min. following the introduction of the light and tone, and for the first and second extinction periods. All six analyses revealed F-ratios which fall short of significance and it can be concluded that the stimuli had no effect, even of a temporary nature, during extinction.

[6] Because means and standard deviations of the raw data were correlated a transformation of the form log $(x + 1)$ was employed in all statistical treatments.

TABLE II

Summary of Conditioning and Extinction Data

Group	Condition	Number of CR's		1st Extinction		2nd Extinction		3rd Extinction	
		Mean Log	σ	Mean Log	σ	Mean Log	σ	Mean Log	σ
I	Light and Tone present throughout Extinction	3.0345	.1187	2.3133	.1131	2.0310	.1319	1.8042	.2088
II	Light and Tone absent throughout Extinction	3.0746	.1280	2.2710	.2433	2.0623	.1836	1.6788	.4969
III	Light and Tone introduced at 26th minute of 1st Extinction period	3.0141	.1410	2.3402	.1233	2.0817	.1865	1.7695	.2408
IV	Light and Tone introduced at 26th minute of 2nd Extinction period	3.0752	.1300	2.4070	.1661	2.1153	.1907	1.8459	.2049

TABLE III

FIRST EXTINCTION PERIOD

Mean log number of responses in the 2-, 4-, and 6-min. periods of Group III following the introduction of the light and tone, and the comparable 2-, 4-, and 6-min. periods of Groups I, II, and IV

Group	2 Min.		4 Min.		6 Min.	
	Mean Log	σ	Mean Log	σ	Mean Log	σ
I	.6991	.3321	.8267	.4134	1.1663	.2241
II	.7303	.4378	1.0490	.4578	1.2170	.4615
III	.8921	.2920	1.1543	.3282	1.3093	.2522
IV	.8609	.2449	1.1289	.3070	1.2860	.2735

A further test of the immediate effect of the stimuli in extinction was carried out as follows: For each S, the rate of response in the 4-min. period following the introduction of the light and tone was compared with the rate of response for the 4-min. period preceding the stimulus presentation. This was done for both the first and second extinction periods for Groups III and IV, respectively. In Group III, where the stimuli were introduced after 26 min. of the first extinction period, it was found that the rate of response following the introduction of the light and tone increased, over the rate preceding the introduction of the stimuli, in 5 out of 17 instances. In the second extinction period, the rate of response, after the introduction of the stimuli, increased in 8 out of 17 instances. These frequencies of increase could readily occur on a chance basis, and it may again be concluded that the introduction of the stimuli resulted in no change in rate during extinction.

TABLE IV

SECOND EXTINCTION PERIOD

Mean log number of responses in the 2-, 4-, and 6-min. periods of Group IV following the introduction of the light and tone, and the comparable 2-, 4-, and 5-min. periods of Groups I, II, and III

Group	2 Min.		4 Min.		6 Min.	
	Mean Log	σ	Mean Log	σ	Mean Log	σ
I	.4670	.3943	.7851	.3158	.9758	.2778
II	.3859	.4505	.6362	.5030	.8064	.4383
III	.4109	.3354	.7200	.3899	.9176	.3820
IV	.6069	.3700	.8899	.3297	.1048	.3129

DISCUSSION

The results of this experiment indicate that the stimuli which were introduced during extinction had no effect on the rate of response, despite the presence of these stimuli whenever the bar-pressing response effected a reinforcement. This finding indicates that it is necessary to permit unreinforced responding in the absence of the positive stimulus in order to give the latter an influence on the strength of the response. All procedures which are known to give a stimulus discriminative control over a response involve differential training (nonreinforcement of the response) with respect to one or more stimuli.

The findings of the present experiment may be compared with the failure of Schoenfeld, Antonitis, and Bersh (9) to give a stimulus secondary reinforcing properties by pairing it in a one-to-one relation with the ingestion of food pellets. Their experiment differed in but one important detail from the procedures employed by investigators who have been successful in giving a stimulus reinforcing properties: The stimulus could in no way become an S^D for any of the responses involved in eating pellets.

The above findings are also consistent with data presented by Notterman (8). He found that a light regularly preceding the procurement of food in the goal box of a runway was

ineffective when tested as a secondary reinforcer. Prior to this test, extinction had been carried out in the dark for 95 trials. Using the same number of light → food trials during acquisition, Notterman randomly interpolated progressively greater numbers of dark → no-food trials (S^{Δ}) for other groups of *S*s. His data show that after the same number of extinction trials in the dark, those groups which had received greater number of S^{Δ} trials during acquisition showed a greater increase in response strength upon reintroduction of the light during the secondary reinforcement test.

Wherever the stimuli in Notterman's experiment acquired reinforcing properties, they had, in addition, discriminative properties (S^{Δ} training) in reference to a latter response in the runway chain. In view of the results of the present experiment, the stimuli used by Schoenfeld, Antonitis, and Bersh (**9**) could not have acquired discriminative properties since there was no opportunity for the response to go unreinforced in the absence of the positive stimulus. It cannot be expected, then, that the stimulus would acquire any control over the rat's operant behavior. This is in accord with the suggestion, by Dinsmoor (**3**) and by Notterman (**8**), that the training procedures necessary for a stimulus to acquire reinforcing or discriminative properties are equivalent.

The results of the present experiment suggest the need for a more precise specification of the role of the stimulus in the stimulus-response-reinforcement contingency. For example, Hull states: "Whenever an effector activity (response) occurs in temporary contiguity with the afferent impulse, or the perseverative trace of such an impulse (stimulus) upon a receptor, and this conjunction is closely associated in time with the diminution in the receptor discharge characteristic of a need (reinforcement), there will result an increment to the tendency for that stimulus on subsequent occasions to evoke that reaction" (**6**, p. 71). The stimulus-response-reinforcement relation employed in the present experiment fulfills the necessary conditions, as specified by Hull, for a stimulus to acquire control over a response. The data, however, show that these stimuli did not, on a subsequent occasion, tend to evoke the response.

Summary

Sixty-eight male albino rats were given aperiodic reinforcement in the continuous presence of a steady tone and a mild intermittent light. Following this training, the *S*s were distributed by lot among four groups and were extinguished for 50 min. on each of three successive days. Group I was extinguished with both light and tone present throughout. Group II was extinguished in the absence of these stimuli. For Group III the light and tone were introduced after 26 min. of the first extinction period had elapsed; for Group IV the light and tone were introduced after 26 min. of the second extinction period had elapsed.

Examination of the data revealed that the presence or absence of these stimuli affected neither the total number of extinction responses nor the rate of response at the time the stimuli were introduced. An analysis of previous studies in which a positive stimulus effect was obtained following similar training indicates the probability that S^{Δ} training was provided for responses in the bar-pressing chain which preceded bar-pressing.

It was concluded that the crucial event in establishing discriminative

control over behavior is the nonreinforced occurrence of the response in the absence of the positive stimulus.

(Manuscript received March 6, 1951)

References

1. Bullock, D. The intercorrelation of the operant rate, the extinction ratio, and the reserve. Conference on the Experimental Analysis of Behavior, Note 15, 1949.
2. Cook, D. A. An experiment on discrimination training without selective reinforcement. Unpublished Master's thesis, Columbia Univ., 1949.
3. Dinsmoor, J. A. A quantitative comparison of the discriminative and reinforcing functions of a stimulus. *J. exp. Psychol.*, 1950, **40**, 458–472.
4. Dinsmoor, J. A. Periodic reinforcement in the presence of a discriminative stimulus. *Amer. Psychologist*, 1950, **5**, 250. (Abstract)
5. Frick, F. C., Schoenfeld, W. N., and Keller, F. S. Apparatus designed for introductory psychology at Columbia College. *Amer. J. Psychol.*, 1948, **61**, 409.
6. Hull, C. L. *Principles of behavior*. New York: Appleton-Century, 1943.
7. Lashley, K. S. The mechanism of vision. III. The comparative visual acuity of pigmented and albino rats. *J. genet. Psychol.*, 1930, **37**, 481–484.
8. Notterman, J. M. A study of some relations among aperiodic reinforcement, discrimination training, and secondary reinforcement. *J. exp. Psychol.*, 1951, **41**, 161–169.
9. Schoenfeld, W. N., Antonitis, J. J., and Bersh, P. J. A preliminary study of training conditions for secondary reinforcement. *J. exp. Psychol.*, 1950, **40**, 40–45.
10. Skinner, B. F. *The behavior of organisms*. New York: Appleton-Century, 1938.
11. Winnick, W. A. A study of incipient movements in avoidance. Unpublished Ph.D. dissertation, Columbia Univ., 1949.

THE EFFECTS OF AUDITORY–VESTIBULAR NERVE PATHOLOGY ON SPACE PERCEPTION [1]

BY CECIL W. MANN

Tulane University

The perception of verticality and horizontality and of the individual's own equilibrium, either on the ground or in fluid media, is mainly the result of visual and proprioceptive factors, acting jointly and reciprocally. In studies designed to investigate the relative contributions of vision and proprioception, the experimental control of visual factors, even to the point of elimination, offers no difficulty. The modification of proprioceptive factors—vestibular mechanisms, cerebellar correlates, postural and righting reflexes, kinesthetic, cutaneous, and organic factors—is a more difficult problem, particularly in human Ss. In view of the difficulty of experimental control of these factors, the importance of the study of individuals with proprioceptive modifications as a result of pathology is apparent.

This study reports the results obtained from a series of experiments on an individual admitted to hospital with abducens nerve palsy resulting from meningeal tuberculosis who subsequently developed paralysis of both auditory and vestibular branches of the VIII nerve following streptomycin therapy. Pathological modification of vestibular and oculomotor factors, probably in unequal amounts, might be expected to yield information concerning the reciprocal and compensatory nature of these factors. Reduced vestibular innervation, particularly if bilaterally differentiated, should result in reduced precision of postural judgment, and also manifest itself in reduced and differentiated nystagmus effects. There should also be reduction of some of the phases of the oculogyral illusion, and differences associated with the direction of rotation might be regarded as indicants of the magnitude of the lesions.

[1] This report is part of a series of investigations conducted jointly with the U. S. Naval School of Aviation Medicine under Contract N7-onr-434, Task Order I, with the Office of Naval Research in cooperation with the Bureau of Medicine and Surgery and the Tulane University of Louisiana. Project No. NR-143-455 of the Medical Sciences Division, Office of Naval Research. Project No. NM 001 063.01 of the Research Division, Bureau of Medicine and Surgery. Task Order Director: Cecil W. Mann.

The Patient

The 22-yr.-old male patient was admitted to the hospital following a brief history of severe, persistent headaches, vomiting, and pain in and rigidity of neck muscles. On admission, he was semi-stuporous; temperature was elevated; respiration irregular; blood pressure was 170/80; neck and back were extended with marked rigidity of the peri-spinal muscles. Laboratory examination revealed a cerebro-spinal fluid pressure of more than 600 mm.; cultures of tubercle bacilli were obtained from the spinal fluid 13 days after inoculation. On the third hospital day, streptomycin therapy was begun. For the first 60 days intramuscular doses of 4 gm. were given every 12 hr. This was reduced at the end of this period to 2 gm. every 12 hr. After 120 days the patient received 1 gm. daily, and this dosage was continued for 12 months. Intrathecal streptomycin (100 mgm. diluted in 10 cc. of distilled water) was given every other day during the first 60 days of therapy. Para-amino salicylic acid in a liquid form was given daily for one year.

During the first two weeks of hospitalization it was noted that the patient had disturbances of the extra-ocular movements of the eyes; there was also a divergent squint. These were thought to be due to damage to the abducens nerve secondary to the tuberculous process in the region of the base of the brain. The extra-ocular function improved during hospitalization and was not clinically manifest on discharge. As early

as the third week of streptomycin therapy, caloric stimulation tests produced no nystagmus. When the patient left his bed at the end of 60 days of therapy, he was unable to maintain equilibrium; the Romberg sign was positive. The patient was retrained in walking, and at the time of discharge was able to walk with his eyes open and with the aid of a cane.

Audiograms taken at monthly intervals showed evidence of hearing loss in the high and low frequencies. Impairment was evident after 30 days of therapy, progressed through the sixth month, and thereafter has remained stationary. The greater loss was in the left ear; approximately 40 db at 128 cycles and 35 db at 1,024 cycles and higher. Loss in the right ear was approximately 25 db at 512 cycles and at 2,048 cycles and above. In the middle range loss in the left ear averaged 30 db; loss in the right ear averaged 15 db.

The diagnoses were: (a) Meningitis, acute, due to mycobacterium tuberculosis, with partial palsy of the abducens nerve; (b) paralysis of VIII cranial nerve, auditory and vestibular branches, secondary to streptomycin therapy.

The patient came to the laboratory during the twelfth and thirteenth months after the beginning of therapy. He was cooperative in all tests; was of good average intelligence and had no difficulty in following directions and reporting his observations. He had made adequate compensation for his VIII nerve paralysis; walked quite easily and comfortably with eyes open. With eyes closed, however, he was unable to balance on one leg, and was able to take only two or three steps before falling.

Two series of tests were planned for the patient; one series was used to determine the precision of his judgments of verticality; the other was designed to ascertain the duration of the oculogyral illusion.

Judgment of Verticality

The postural vertical.—In this test, *S* was required, in the absence of visual cues, to align himself to the direction of the pull of gravity from positions of lateral inclination. This was done by requiring *S* to return himself to the vertical in the Tulane tilt chair. This consists of a sturdy wooden chair designed to permit lateral tilting in right and left quadrants. The shaft from a reversible electric motor is attached to the back of the chair at a position corresponding approximately to the center of gravity of an adult in a seated position. The chair can move clockwise at .5 rpm; counterclockwise at .35 rpm. Dual controls make possible the control of the movement by *E* or *S*. Remote recording of the movement of the chair is provided by a selsyn circuit, the accuracy being of the order of .5°. The *E*'s control and recording devices are in a room adjacent to the room housing the tilting chair. The chair is provided with a headrest to ensure that the axes of *S*'s head and body are in alignment during the trials. Modification of somesthetic stimuli, by reduction of the pressures on the sides of the body and on the buttocks, is possible by the insertion of a thin iron framework thickly padded with sponge rubber which fits the chair closely.

Using normal adults, Mann, Berry, and Dauterive (10) found that their *S*s, on a hard unpadded seat, were able to return to the postural vertical from positions of inclination up to 90° with a mean constant error of .8° and a variable error of 1.9°. With the insertion of the soft padded seat there was no significant increase in constant error but a significant increase in variable error to 3.4°. In later studies, Mann and Passey (11) and Passey and Guedry (18) compared the judgments made when *S* returned himself to the postural vertical immediately from positions of lateral tilt (no delay), with those made when *S* was delayed in the tilted position for 60 sec. before returning to the vertical (delay). Under condition of delay, there was found an increase in average error, an increase in constant error in the direction of tilt, and an increase in the frequency of judgments in the direction of tilt. Other experiments in this laboratory have produced similar results.

It is concluded that the normal individual can, in the absence of visual stimulation, make perceptions of the postural vertical with a constant error of less than 1°, and that under conditions of delayed inclination there is adaptation.

The tests of postural judgment administered to the patient in the present series were comparable to those given normal adults. Inclinations of 10°, 20°, 30°, and 40° in each quadrant were randomized, and conditions of hard and soft seat, no delay and delay were introduced. Two trials were made in each condition; a total of 64 trials. Statistical tests supported the assumption of homogeneity of variance, and since no significant differences were found in right and left quadrants and in each of the angles of inclination, the right and left quadrants were thrown together for analysis.

The results shown in Table I indicate that the constant errors made

TABLE I

MEAN ERRORS IN DEGREES IN THE JUDGMENT OF THE POSTURAL VERTICAL UNDER CONDITIONS OF HARD AND SOFT SEAT, AND NO DELAY AND DELAY
(N = 16 each condition)

Mean Error	Hard Seat		Soft Seat	
	No Delay	Delay	No Delay	Delay
Constant	+3.00*	+3.25*	+2.81*	+3.09*
Variable	1.33	1.07	1.36	1.02

* The plus sign indicates the judgment is in the quadrant opposite to that of tilt.

by S were far in excess of those made by normal adults, but that the variable errors were, if anything, less. It might be expected that loss of vestibular stimulation would produce less precise judgments of the postural vertical. Perhaps more important than this is the fact that the indices of adaptation are absent. There are no significant differences in error between conditions of no delay and delay, nor is there any tendency for the constant error to shift towards the quadrant of inclination. Of the 32 trials under conditions of delay, in only one trial was the error in the direction of inclination. It is concluded that for this patient, judgment of the postural vertical is impaired, and there is no evidence of adaptation to inclination.

The visual vertical.—Visual judgments were made of a narrow luminous line produced by a modified Navy collimated star (Mark II). The reticle of the collimator was driven by a reversible motor controlled by S or E. Remote recording was possible by the use of a selsyn circuit. A modified repeater-type altimeter served as recorder and accuracy was possible to within .04°. The device was rigidly attached to the chair at S's eye level, and moved with the chair when the latter was inclined. A head clamp was used to keep the head and body axes in alignment during the trials.

Using normal adults, Mann, Berry, and Dauterive (10) found that their Ss, when seated in an upright position with head and body axes in alignment, made a mean constant error of .3° in the judgment of the visual vertical. In a series of judgments of the visual vertical made from positions of right and left body tilt, Jones (8) found that normal adults increased their constant error up to body tilt of 45°, the error being less than the amount of body tilt and in the opposite quadrant.

In the present series, the patient was first required to return the collimated line to visual vertical from positions of 15° in right or left quadrants, arranged in random order. This was followed by a series of judgments from positions of body inclination. The target was first adjusted to the gravitational vertical; then the chair, the target, and the S were moved to a position of tilt. When the chair was stopped, the axis of the target line, the head, and the body axes were in alignment. The S was then required to adjust the target line to the gravitational vertical by means of the control switch on the arm of the chair. Before the series was begun, S understood clearly that his goal at all times was to adjust the target line parallel to the walls of the room. Three positions of body tilt in each quadrant were used, 10°, 20°, and 30°; and ten trials were made from each position, a total of 60 trials.

Mean constant and variable errors are shown in Table II. Statistical analysis of the data provided no basis for the rejection of the hypothesis of homogeneity of variances. Analysis of variance yielded an F of 439.46 (df = 1 and 58) for right and left quadrants and an F of 22.98 for in-

TABLE II

MEAN ERRORS IN JUDGMENT OF THE VISUAL VERTICAL FROM POSITIONS OF LATERAL BODY TILT

Quadrant	Error	Body Tilt			
		0°	10°	20°	30°
Left	Constant	+1.80*	+5.80	+9.36	+13.36
	Variable	0.62	0.93	1.00	1.47
Right	Constant	+0.80	+3.24	+6.05	+ 9.79
	Variable	0.31	1.21	1.44	1.62

* The plus sign indicates the judgment is in the quadrant opposite to that of tilt.

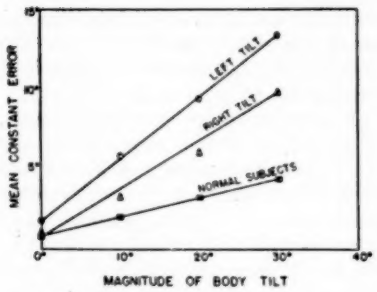

FIG. 1. Mean constant errors of judgment of the visual vertical made by the patient from positions of lateral tilt in right and left quadrants. Mean constant errors made by intact *S*s in right and left quadrants are combined.

teraction between quadrants and angles of tilt. Both are significant at the .01 level of confidence.

Comparisons may be made with the data on normal adults collected by Jones (**8**). He found no significant differences between errors made in right and left quadrants. Since he used angles of inclination different from those used in this experiment, the values used for the comparison have been calculated from the equation of best fit obtained by the method of least squares. The data are graphically represented in Fig. 1.

It will be seen that in each of the positions of tilt investigated the patient made errors greatly in excess of those made by Jones's normal adults, and that his errors are significantly greater for tilt in the left quadrant than for that in the right. All constant errors in Table II are in the quadrant opposite that of inclination.

ROTATIONAL EFFECTS

The equipment for the determination of rotational effects was a chair on a vertical axis driven by a reversible motor at speeds up to 25 rpm. The visual target was a $3 \times 3 \times 6$ in. rectangular box, on one side of which were drilled eight holes .5 in. in diameter, illuminated by a lamp sufficiently bright to be seen by *S* but not bright enough to make visible the walls of the room. The box was lined with white bond paper in order to diffuse the light. The target was firmly attached to the chair at eye level and at a distance of 6 ft. from *S*. The chair was provided with a bite-board which served to keep *S*'s head fixed and tilted slightly forward during the trials. The room was light-tight, and to ensure complete absence of any reflected light from the target, the walls were draped from ceiling to floor with black cloth suspended from a circular framework. The chair was run at 20 rpm and constant velocity was reached in less than 2 sec. The device can be stopped in approximately the same time by a hydraulic braking system. The *S* signalled his reports by means of a key on the arm of his chair. A Standard Electric timer was used to measure time intervals.

Graybiel and Hupp (**5**) have described the oculogyral illusion as follows: (a) with the onset of rotation the target appears to move in the direction of rotation (first effect during rotation); (b) following a latency period of 1—5 sec., the target appears to move in the opposite direction (second effect during rotation); (c) upon cessation of rotation, the target appears to move rapidly in the direction opposite to that of rotation (first effect following rotation); (d) following a latency period of a few seconds the target appears to move in the direction of rotation (second effect following rotation).

It is possible that under ideal conditions, and with acceleration equal to deceleration, the duration of the first effects, during and after rotation, would be equal. It has been shown by Graybiel and Hupp (**5**) and Guedry (**7**) that duration of the first effects ranges from about 20 to 30 sec. In a recent study of normal adults under 30 yr. of age, Guedry (**6**) obtained a mean of 24.70 sec. for the first effect after rotation, with a standard deviation of 5.56 sec. No difference was found in normal *S*s between results obtained in clockwise or in counterclockwise directions.

In the present series the patient was subjected to ten trials in each direction, twenty trials in all, at a velocity of 20 rpm. The mean duration of the first effect *after* rotation was 4.0 sec. for clockwise rotation (to the right) and 2.8 sec. for counterclockwise rotation (to the left). These differences are significant at the .01 level of confidence. For none of the trials was he able to report the first effect *during* rotation. This effect is more difficult to report, and was probably missed by the patient because of its short duration.

Discussion

Postural judgment.—The effects of the toxic reactions of streptomycin on the VIII nerve have been discussed by Brown and Hinshaw (**2**). Glorig and Fowler (**4**) in a clinical examination of 32 *S*s found impaired hearing, and reduction or loss of reaction to rotation and to caloric stimulation. By the use of the tilt table, they found that sudden tilt produced falling in the direction of tilt, but that their *S*s were able to compensate for the effect of slow tilt.

In the present series it was found that the judgment of the postural vertical was less precise than that of intact *S*s. Moreover, the patient did not exhibit the adaptation to inclination found in intact *S*s.

Visual judgment.—In 1861, Aubert (**1**) pointed out that when a vertical luminous line was observed in a dark room with head inclined to the body, the line appeared to be displaced in the opposite quadrant (Aubert or *A* effect). Feilchenfeld (**3**) found that with large head inclinations the displacement was as much as 50° or 60° in the opposite quadrant, but that in all cases the displacement of the line was less than the angle of body inclination. In 1916, Müller (**14**) showed that with small head inclinations the displacement of the line was in the same quadrant as the head inclination (Müller or *E* effect).

The magnitudes of displacements of the line target obtained in the Tulane experiments are much less than those reported by the above experimenters. The maximum displacement with intact adults, reported by Jones (**8**), was 12° at a body inclination of 45°. Moreover, the displacements were predominantly in the opposite quadrant, exemplifying the Aubert effect. It should be pointed out that in the Tulane experiments a bite-board was used, so as to maintain the head and body axes in alignment. In the German experiments the head was inclined to the body, thus permitting the operation of neck reflexes. This may account for the different results.

Aubert (**1**) also pointed out that the displacement occurred in the absence of surrounding visual stimulation; as soon as the room was illuminated the line appeared to return to the vertical. Passey (**17**) required his *S*s to return a tilting room to the vertical while seated in a chair independently set at different positions of body tilt. Under these extended visual conditions the maximum mean constant error was 2.3°, made when his *S*s were in a position of 20° body tilt. This is somewhat less than the constant error of 3.3° from the same angle of body tilt obtained by Jones (**8**), who used the luminous line as the visual target, and is in keeping with Aubert's results.

The errors made by the patient in the present series, using the line target, are all in the quadrant opposite that of body tilt, and are much greater than those obtained by intact *S*s. Since the bite-board held the body and head axes in alignment, we may

rule out neck reflexes as a contributing factor. It has been shown by Mulder (12, 13) and Nagel (15, 16) that with head inclination there is counter-rolling of the eyes, ranging in magnitude from $\frac{1}{12}$ to $\frac{1}{2}$ of the amount of body or head inclination. The effect of counter-rolling would be to reduce the Aubert effect. In our patient, however, the constant errors exceed those made by intact adults, and since even for the relatively small magnitudes of body tilt they are always in the direction of the Aubert effect, an argument can be made either for the absence of counter-rolling or for lack of vestibular compensation.[3]

The errors made in positions of left body inclination are significantly greater at all angles than those made in right inclination. If it is agreed that the intact vestibule exerts an effect compensatory for body tilt, then these results would support the position that innervation from both vestibules is reduced, and the greater error from positions of left inclination would indicate that innervation from the left vestibule is less than that from the right.

Oculogyral illusion.—In his study of deaf-mutes, Kreidl (9) found reduction or loss of nystagmus. In our patient the duration of the first effect during rotation was too short to observe, and the duration of the first effect following rotation was much less than that observed by intact *Ss*. Stefani (19) has suggested (a) that each canal is excited by rotatory movements in its own plane, and (b) that rotatory movement to the right excites the canals of the right side in preference to those of the left side, and vice versa. Examination of our results in the light of these findings indicates that the innervation of the left vestibule is less than that of the right. The consistent finding in our patient of greater innervation from the right auditory-vestibular nerve is supported by the audiograms; at all frequencies the hearing loss is greater in the left ear than in the right.

[3] Investigations made by Dr. W. Fletcher McCord subsequent to this experimental series confirmed this prediction; the counter-rolling reflex was found to be absent in this subject for inclination in both right and left quadrants.

Conclusions

The results of this series of tests indicate that paralysis of the auditory-vestibular nerve produces reduced precision of judgment of the postural vertical and absence of adaptation to postural inclination; increased error of judgment of the visual vertical from positions of postural tilt and in the direction of the Aubert effect, and reduced nystagmus and oculogyral effects. The absence of the Müller effect and the increase in the Aubert effect over that found in intact adults appear to be evidence for the compensatory function of the vestibular mechanism when the head or the body are laterally inclined. This supports the hypothesis that the perception of verticality in intact individuals is determined by the joint reciprocal action of the visual and proprioceptive stimulus variables.

(Manuscript received for priority publication July 12, 1951)

References

1. Aubert, H. Eine scheinbare bedeutende Drehung von Objecten bei Neigung des Kopfes nach rechts oder links. *Arch. f. pathol. Anat.*, 1861, 20, 381–393.
2. Brown, H. A., and Hinshaw, H. C. Toxic reactions of streptomycin on the eighth nerve apparatus. *Proc. Mayo Clin.*, 1946, 21, 347.
3. Feilchenfeld, H. Zur Lageschätzung bei seitlicher Kopfneigung. *Z. Psychol.*, 1903, 31, 127–150.

4. Glorig, A., and Fowler, E. P. Tests for labyrinth function following streptomycin therapy. *Ann. Otol. Rhinol. & Laryngol.* 1947, **56** (2), 379–395.
5. Graybiel, A., and Hupp, D. I. The oculogyral illusion: A form of apparent motion which may be observed following stimulation of the semicircular canals. *J. aviat. Med.*, 1946, **17**, 3–27.
6. Guedry, F. E. Age as a variable in post-rotational phenomena. U. S. Naval Sch. Aviat. Med. & Tulane Univ. Joint Report No. 19, 1950.
7. Guedry, F. E. The effect of visual stimulation on the duration of post-rotational apparent motion effects. *J. gen. Psychol.*, 1950, **43**, 313–322.
8. Jones, D. B. Judgment of the visual horizontal and vertical from positions of lateral body tilt. Unpublished master's thesis, Tulane Univ., 1950.
9. Kreidl, A. Beiträge zur Physiologie des Ohrlabyrinths auf Grund von Versuchen an Taubstummen. *Pflügers Arch. ges. Physiol.*, 1892, **51**, 119–150.
10. Mann, C. W., Berry, N. H. B., and Dauterive, H. J. The perception of the vertical: I. Visual and non-labyrinthine cues. *J. exp. Psychol.*, 1949, **39**, 538–547.
11. Mann, C. W., and Passey, G. E. The perception of the vertical: V. Adaptation effects. U. S. Naval Sch. Aviat. Med. & Tulane Univ. Joint Report No. 9, 1949.
12. Mulder, M. E. De la rotation compensatrice de l'oeil en cas d'inclination à droits ou à gauche de la tête. *Arch. Ophthal.*, Paris, 1897, **17**, 465–474.
13. Mulder, M. E. Ons oordeel over verticaal, bij neiging van het hoofd naar rechts of links. *Arch. Anat. u. Physiol.*, 1888, **2**, 340–352.
14. Müller, G. E. Ueber das Aubert'sche Phänomen. *Z. Psychol. Physiol. Sinnesorg.*, 1916, **49**, (II), 109–244.
15. Nagel, W. A. *Handb. d. Physiol. d. Menschen.* 1905. Vol. III, 734–806.
16. Nagel, W. A. Ueber das Aubert'sche Phänomen und verwandte Täuschungen über die vertikale Richtung. *Z. Psychol. Physiol.*, 1898, **16**, 373–398.
17. Passey, G. E. The perception of the vertical: IX. Adjustment of the visual vertical from various magnitudes of body tilt. U. S. Naval Sch. Aviat. Med. & Tulane Univ. Joint Report No. 15, 1950.
18. Passey, G. E., and Guedry, F. E. The perception of the vertical. II. Adaptation effects in four planes. *J. exp. Psychol.*, 1949, **39**, 700–707.
19. Stefani, A. Della funzione non acustica o di orientamento del labirinto dell'orecchio. *Atti del R. Ist. Veneto di Sci. Lett. ed Arti*, 1903, **62**, 937–1019, 1121–1151.
20. Witkin, H. A., and Asch, S. E. Studies in space orientation: III. Perception of the upright in the absence of a visual field. *J. exp. Psychol.*, 1938, **38**, 603–614.

JOURNAL OF EXPERIMENTAL PSYCHOLOGY

The issues listed below are available for sale

Year	Volume	Available Numbers						Price per Number	Price per Volume
1916	1	1	2	3	4	5	6	$1.25	$7.00
1917	2	1	2	–	4	5	–	$1.25	$5.00
1920	3	–	2	–	4	5	–	$1.25	$3.75
1921	4	1	–	3	4	5	6	$1.25	$6.25
1922	5	–	–	3	4	5	–	$1.25	$3.75
1923	6	–	–	–	–	–	–	——	——
1924	7	1	2	–	–	5	–	$1.25	$3.75
1925	8	1	2	3	4	–	6	$1.25	$6.25
1926	9	–	2	3	–	5	6	$1.25	$5.00
1927	10	–	–	3	4	5	6	$1.25	$5.00
1928	11	1	2	3	4	5	6	$1.25	$7.00
1929	12	1	2	3	4	5	6	$1.25	$7.00
1930	13	1	2	3	4	5	6	$1.25	$7.00
1931	14	1	2	3	4	5	6	$1.25	$7.00
1932	15	1	2	3	4	5	6	$1.25	$7.00
1933	16	1	2	3	4	5	6	$1.25	$7.00
1934	17	1	2	3	4	5	6	$1.25	$7.00
1935	18	1	2	3	4	5	6	$1.25	$7.00
1936	19	1	2	3	4	5	6	$1.25	$7.00
1937	20	1	2	3	4	5	6	$1.25	$7.00
	21	1	2	3	4	5	6	$1.25	$7.00
1938	22	1	2	3	4	5	6	$1.25	$7.00
	23	1	2	3	4	5	6	$1.25	$7.00
1939	24	1	2	3	4	5	6	$1.25	$7.00
	25	1	2	3	4	5	6	$1.25	$7.00
1940	26	1	2	3	4	5	6	$1.25	$7.00
	27	1	2	3	4	5	–	$1.25	$6.25
1941	28	1	2	3	4	5	6	$1.25	$7.00
	29	1	2	3	4	5	6	$1.25	$7.00
1942	30	1	2	3	4	5	6	$1.25	$7.00
	31	1	2	3	4	5	6	$1.25	$7.00
1943	32	1	2	3	4	5	6	$1.25	$7.00
	33	1	2	3	4	5	6	$1.25	$7.00
1944	34	1	2	3	4	5	6	$1.25	$7.00
1945	35	1	2	3	4	5	6	$1.25	$7.00
1946	36	1	2	3	4	5	6	$1.25	$7.00
1947	37	1	2	3	4	5	6	$1.25	$7.00
1948	38	1	2	3	4	5	6	$1.25	$7.00
1949	39	1	2	3	4	5	6	$1.25	$7.00
1950	40	1	2	3	4	5	6	$1.25	$7.00
1951	41	1	2	3	4	5	6	$1.25	$7.00
	42	1	2	3	4	5	6	$1.25	$7.00
1952	43	By subscription, $14.00 (2 vols.)						$1.25	——
	44								
		List price, Volumes 1 through 42							$269.00
		30% discount							80.70
		Net price, Volumes 1 through 42							$188.30

Information about the Journal of Experimental Psychology: as noted in the table, the journal was not published in 1918 and 1919; from 1937 to 1943 it was published at the rate of two volumes per year; from 1944 to 1950, in one volume per year. Beginning in 1951 there are two volumes a year.

Information about prices: when all numbers are available, the price per volume throughout the series is $7.00. For incomplete volumes, the price is $1.25 for each available number. For foreign postage, $.25 per volume should be added. The American Psychological Association gives the following discounts on orders for any one journal:

10% on orders of $ 50.00 and over
20% on orders of $100.00 and over
30% on orders of $150.00 and over

Address orders and subscriptions to

AMERICAN PSYCHOLOGICAL ASSOCIATION

1515 Massachusetts Avenue N.W. Washington 5, D. C.

JUST PUBLISHED

CEREBRAL MECHANISMS in BEHAVIOR

The Hixon Symposium (Cornell University, 1948). Edited by LLOYD A. JEFFRESS, *The University of Texas.* Includes seven papers by leading psychologists, psychiatrists, biologists, etc., on cerebral function and behavior, plus the discussions of each paper by other leading scientists.

1. *The General and Logical Theory of Automata*, by DR. JOHN VON NEUMANN. Considers what automata can do and proposes a new concept, complication, in connection with an analysis of the problem of self-reproduction of automata.

2. *Why the Mind is in the Head*, by DR. WARREN S. MCCULLOCH. Considers how a digital machine might operate to perform some of the feats our brains perform, including the perceptual "constancies."

3. *The Problem of Serial Order in Behavior*, by DR. K. S. LASHLEY. Treats this important, largely neglected problem—which involves language, rhythmical acts, skills, etc.—and suggests how such ordering might be accomplished in the brain.

4. *Functional Differences between the Occipital and Temporal Lobes*, by DR. HEINRICH KLÜVER. Deals with porphyrins and with "equivalent stimuli" in connection with cerebral function.

5. *Relational Determination in Perception*, by DR. WOLFGANG KÖHLER. Presents the first account of the author's work in the electro-physiology that may underlie the phenomenon of figural after-effect.

6. *Brain and Intelligence*, by DR. WARD HALSTEAD. Discusses the problem of biological intelligence and offers a new hypothesis of protein organization and mental function.

7. *The Symposium from the Standpoint of a Clinician*, by DR. HENRY W. BROSIN. Summarizes the views expressed during the Symposium and considers many of the problems left untouched.

1951 311 pages $6.50

Send for a copy on approval

JOHN WILEY & SONS, Inc., 440-4th Ave., New York 16, N.Y.